Experimental Techniques Lecture 3

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Unfolding

When?

Use unfolding to recover theoretical distribution where

- There is no a-priori parameterisation (otherwise can just fit to function!)
- This is needed for the result and not just comparison with MC
- There is significant bin-to-bin migration of event

Where?

- Traditionally used to extract structure functions
- Dalitz plots: cross-feed between bins due to misreconstruction
- “True” decay momentum distributions

  Theory at parton level, we measure hadrons

  Correct for hadronisation as well as detector effects

How?

- Can sometimes get away with simple iterative procedure
- If low statistics in bins, "spiky", need to smooth $\longrightarrow$ "regularization"
- Packages out there, e.g., RooUnfold, works in root.

Also see: A SURVEY OF UNFOLDING METHODS FOR PARTICLE PHYSICS
G. Cowan, http://www.ippp.dur.ac.uk/old/Workshops/02/statistics/proceedings/cowan.ps

Outline

Measuring particle properties: e.g., Top quark mass

- Different ways to extract from observables
- Blind analyses

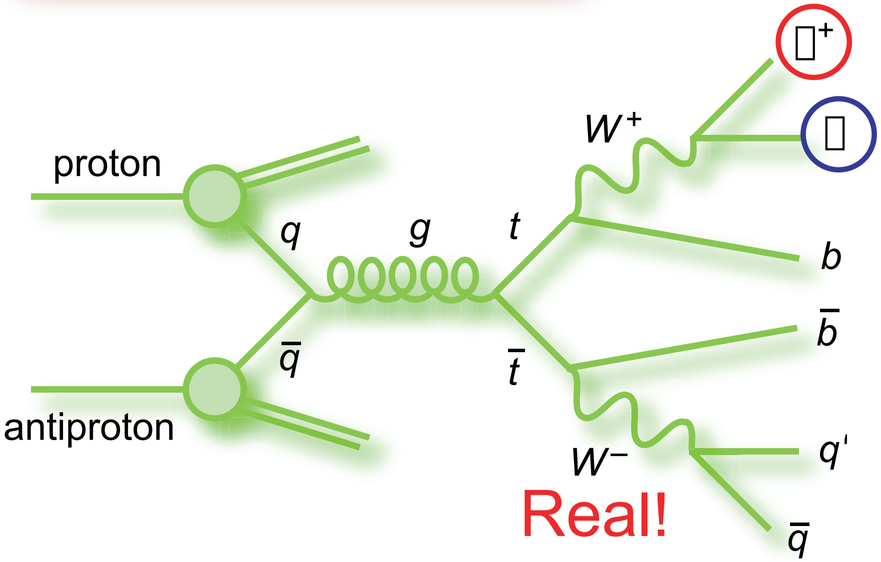
W mass

Searches for new particles/phenomena e.g., GMSB SUSY

- Event selection
- Multivariate Techniques
- Backgrounds
- Limits

Top Quarks

...back to measuring top mass...



Require

isolated lepton + missing E_T + jets

- Needs excellent understanding of entire detector! Triggering, tracking, b-tags, electrons, muons, jets, $\not{E}_T$
- Performance must be understood and modelled well
- Dominant background will be W + jets (including W + 2 b-jets!)

Four quarks in the $t\,\bar{t}$ partonic final state
Require 4 jets?
No! Number partons ≠ Number jets!

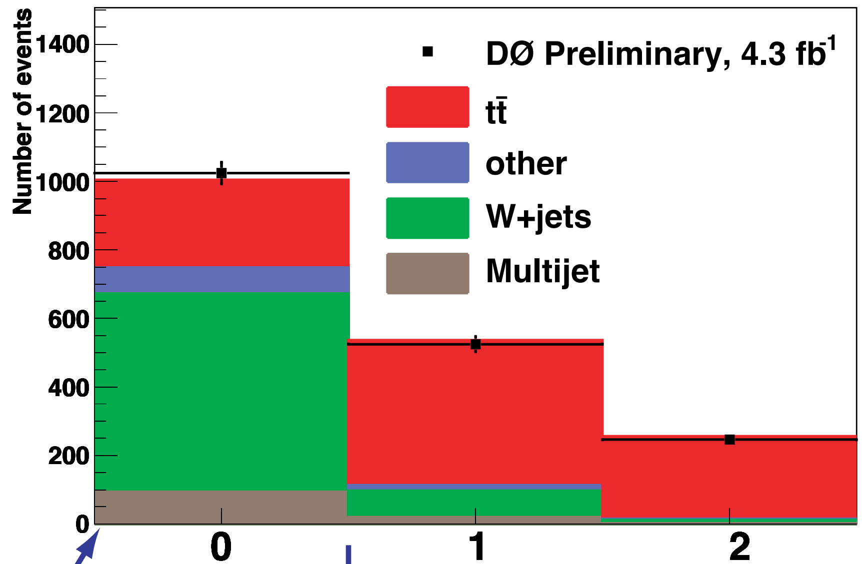
- More jets from
  gluon radiation from initial or final state
- Fewer jets from
  overlaps (merged in reconstruction)
  inefficiencies or cracks in detector
  fall outside □ acceptance or below p_T cut

Top Quarks

First, b-tag:

Since typical *b*-tagging efficiency ~50%, then for final state with two *b* jets,

Prob(2 tags) ~ 25%
Prob(1 tag) ~ 75%



Signal region

Control region
(particularly for lower N_{jet})
Verify background modeling

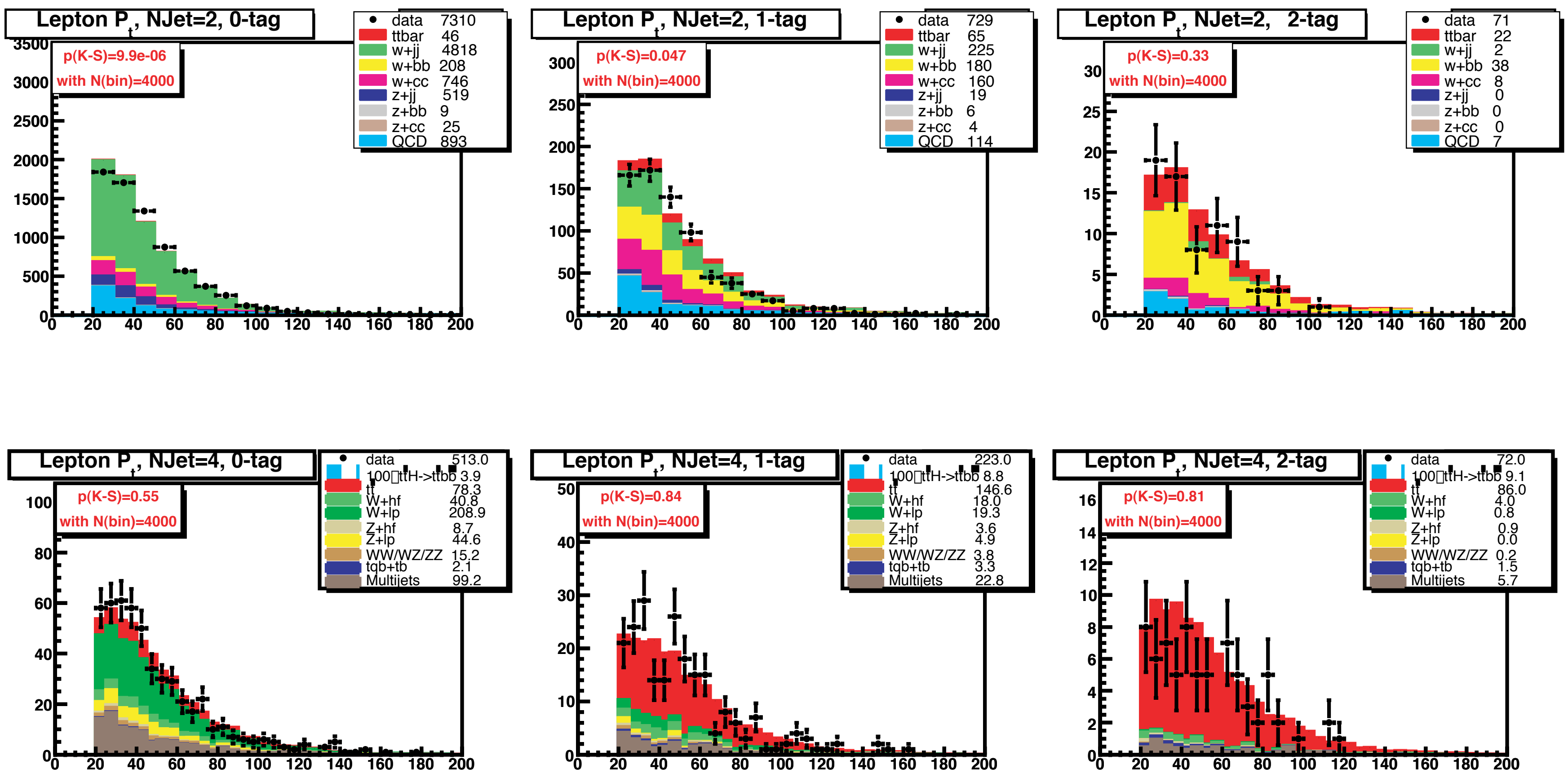
Top Quarks

Understanding of backgrounds & assigning uncertainty

$0\,b-\mathrm{jet\ tags}$ $\quad$ $1\,b-\mathrm{jet\ tags}$ $\quad$ $2\,b-\mathrm{jet\ tags}$

$N_{\mathrm{jet}} = 2$

$N_{\mathrm{jet}} = 4$



Background determined in control regions, extrapolated to signal region

Top Quarks — Matrix Element Method for Mass

Construct probability density function as function of m_{top} for each event

$$P_{\text{sig}}(\vec{x}, m_{\text{top}}, JES) \propto \sum w_n \int_{q_1, q_2, \vec{y}} |\mathcal{M}(p\bar{p} \to t\bar{t} \to \vec{y})|^2 dq_1 dq_2 f(q_1) f(q_2) d\Phi_6 W(\vec{x}, \vec{y}, JES)$$

Weight that jet is a b-jet

Matrix Element (lepton + jets)

Parton PDF's

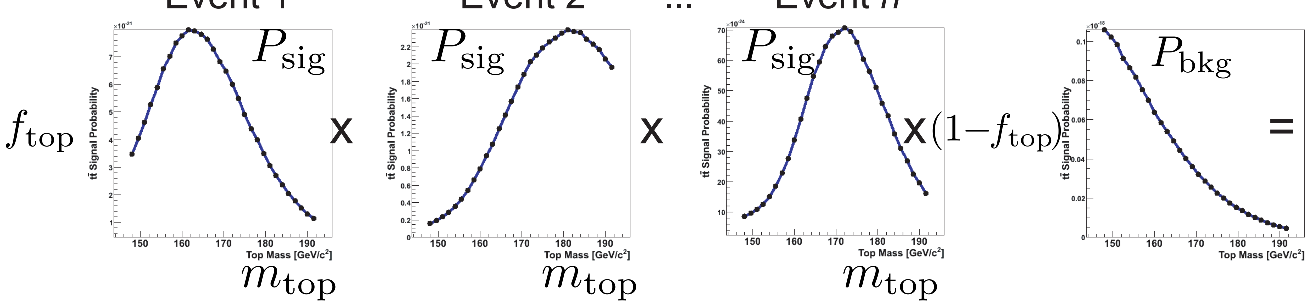
Observed kinematics (e.g., parton,lepton, neutrino 4-vectors) of event

Transfer function

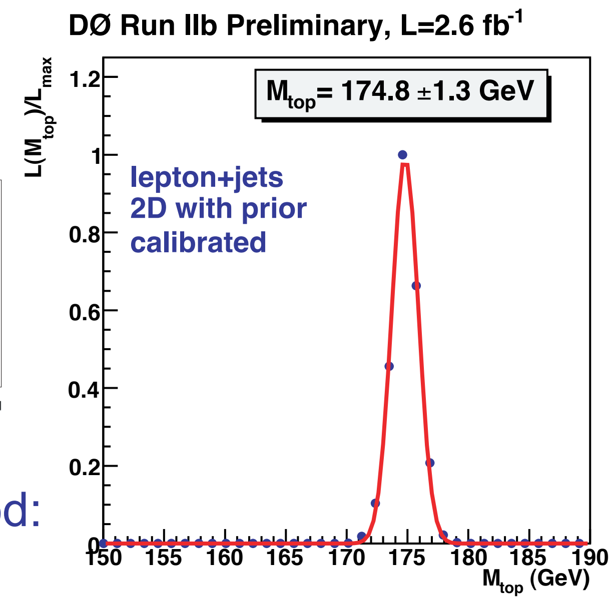
Parton kinematics of event

Calculating the probability for an event to be consistent with a *tt* decay for a given m_{top}

4-vectors with maximal topological information + correlations, maximal possible use of event info



Multiply probabilities for all the events for overal likelihood:



Top Quarks

Matrix Element Method for Mass

Construct probability density function as function of m_{top} for each event

Jet energy scale

$$P_{\mathrm{sig}}(\vec{x}, m_{\mathrm{top}}, JES) \propto \sum w_n \int_{q_1,q_2,\vec{y}} |\mathcal{M}(p\bar{p} \to t\bar{t} \to \vec{y})|^2 dq_1 dq_2 f(q_1) f(q_2) d\Phi_6 W(\vec{x}, \vec{y}, JES)$$

Matrix Element (lepton + jets)

Parton PDF's

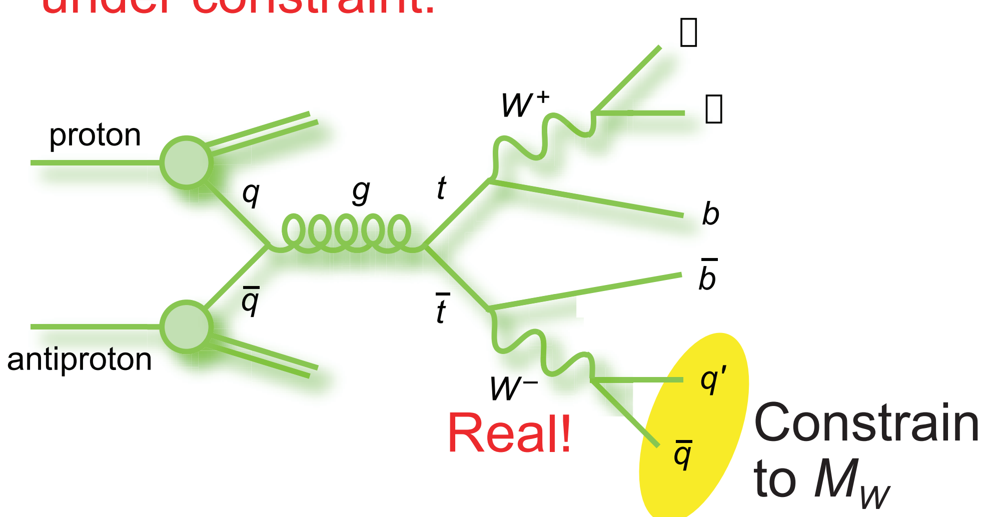
Observed kinematics (e.g., parton,lepton, neutrino 4-vectors) of event

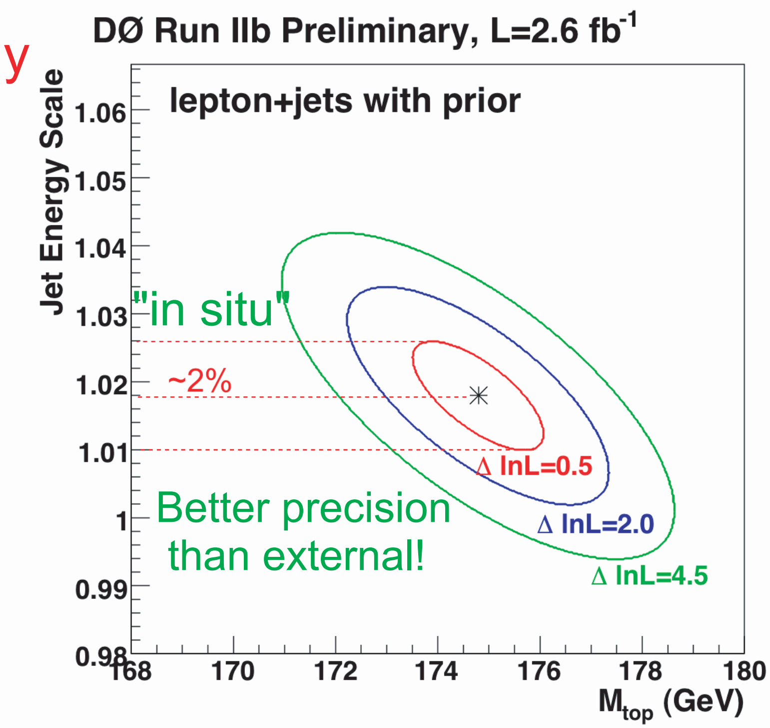
Weight that jet is a b-jet

Parton kinematics of event

Transfer function

Bonus! Knowledge of jet energy scale usually a dominantsystematic uncertainty – let float under constraint:

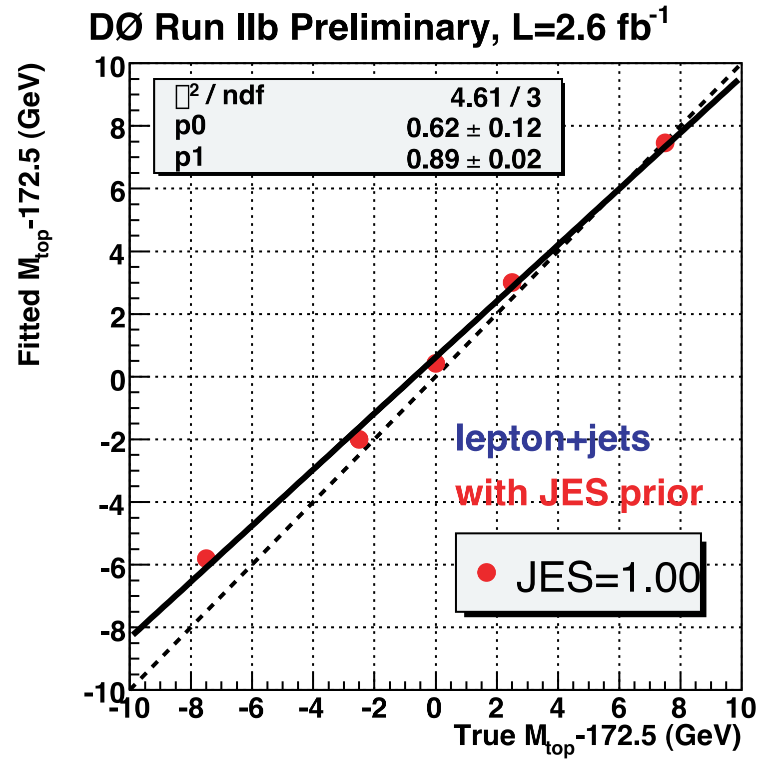


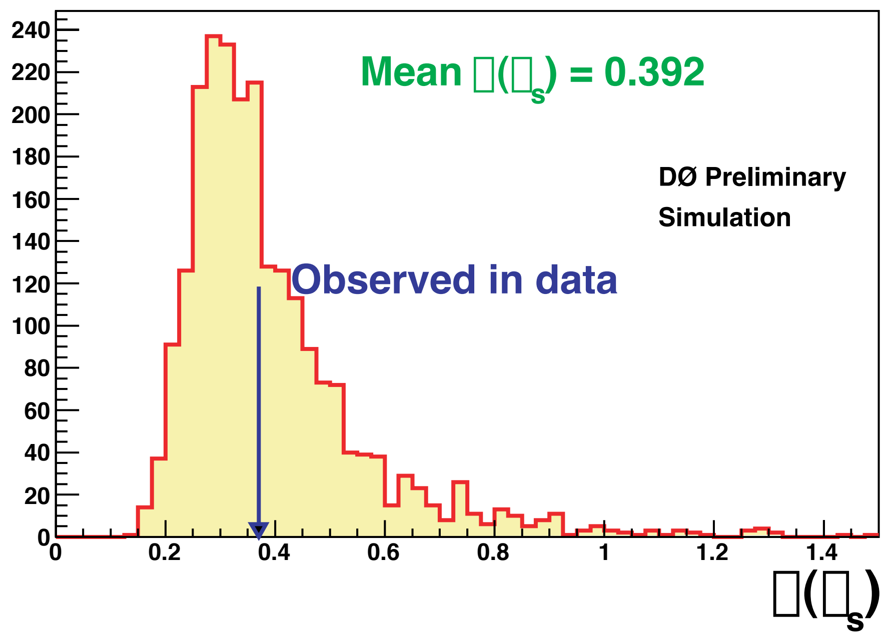


Top Quarks

Calibration/Check of analysis

The other essential role of MC
when measuring a property:
vary true value in MC, fit as if data:





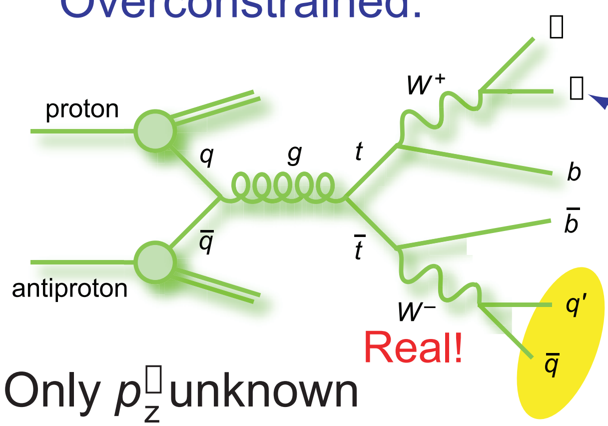
...and is fitted value and
its uncertainty consistent with
expectations? *Ensembles* of
MC events, statistics same as data
("luckiness")

Top Quarks

Template Method

- Identify variables $\vec{x}$ sensitive to parameter of interest (e.g., $m_{\rm top}$)

Overconstrained:



Constrain to M_W

$$\chi^2 = \sum_{\rm jets} \frac{(P_T^{i,\rm fit} - P_T^{i,\rm meas})^2}{\sigma_i^2} + \cdots \text{ Four vectors}$$

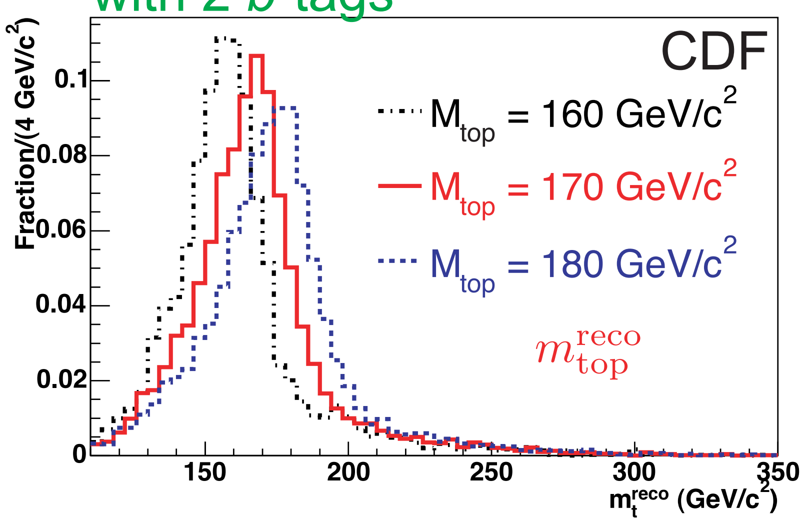
$$+ \frac{(M_{jj} - M_W)^2}{\Gamma_W^2} + \frac{(M_{\ell\nu} - M_W)^2}{\Gamma_W^2}$$

$$+ \frac{(M_{bjj} - m_{\rm top}^{\rm reco})^2}{\Gamma_t^2} + \frac{(M_{b\ell\nu} - m_{\rm top}^{\rm reco})^2}{\Gamma_t^2}$$

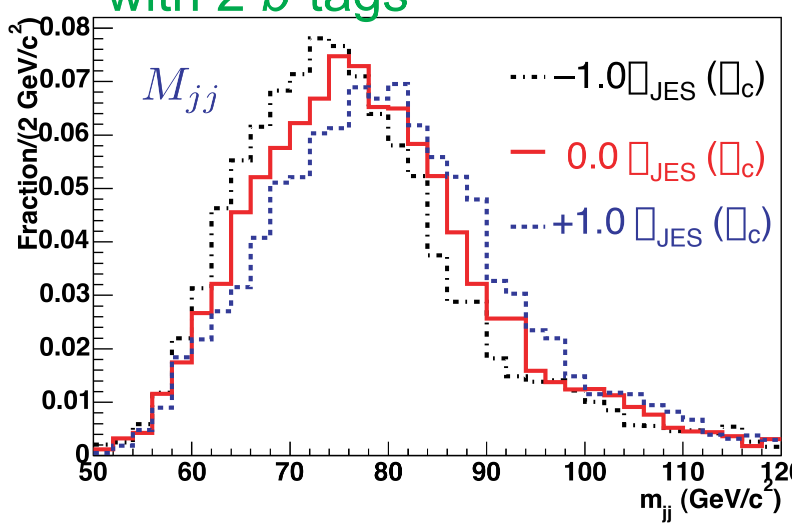
Minimize Each Event

- Using MC, generate signal distribution of $\vec{x}$ as a function of $m_{\rm top}$

with 2 *b*-tags



with 2 *b*-tags

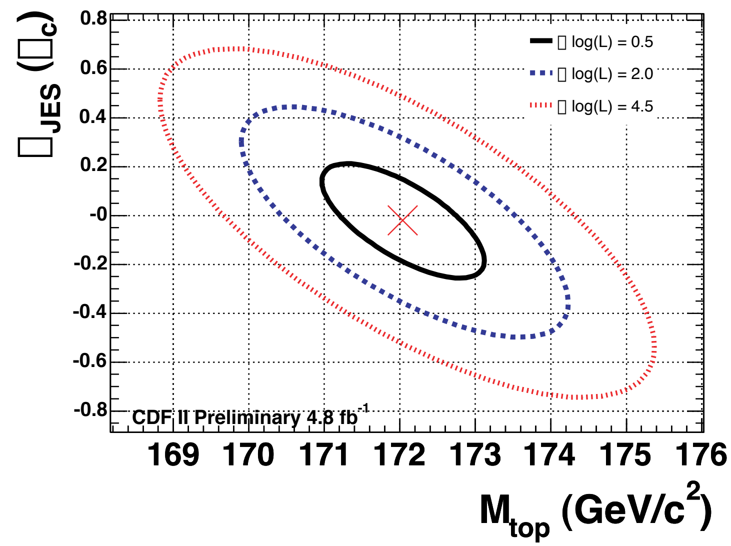


Top Quarks

Template Method

- Probability density functions for $m_{\text{top}}^{\text{reco}}$, M_{jj} for each point in a $(m_{\text{top}}, \Delta_{\text{JES}})$ grid using Kernel Density Estimate (KDE) approach
  → a non-parametric method for forming density estimates that can easily be generalized to more than one dimension

- Minimize likelihood of whole sample:



- Individual top quark mass measurements have a precision just under 1% → ***Hard!***

- Measurements with precision less than 0.1%? → ***Hardcore!***

W Mass

- A simple topology, but want crazy-good precision
- Use variables only in transverse plane

$$p_T^e \,, \not{E}_T \,, m_T$$

$$m_T = \sqrt{2 p_T^e E_T (1 - \cos\Delta\phi_{e-\nu})}$$

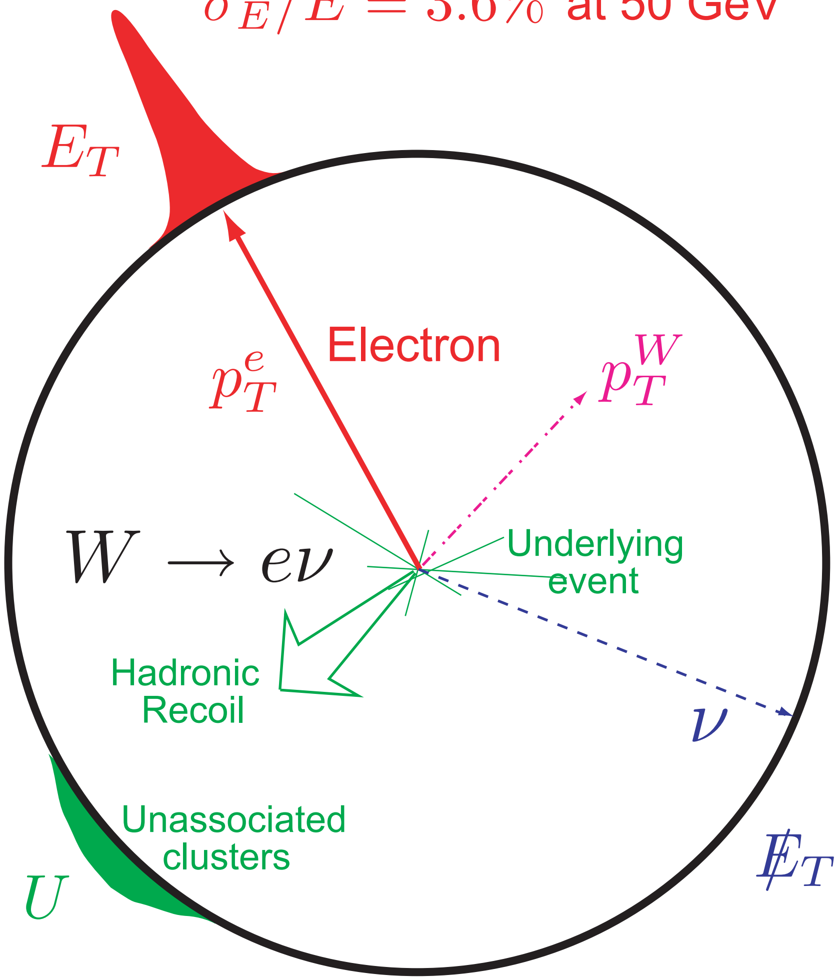
Less sensitive to knowledge of p_T^W

(zero at LO; non-zero at NLO)

- Use knowledge of hadronic recoil through those unassociated clusters to make p_T^e and $\not{E}_T$ less sensitive to the transverse motion of the *W* boson

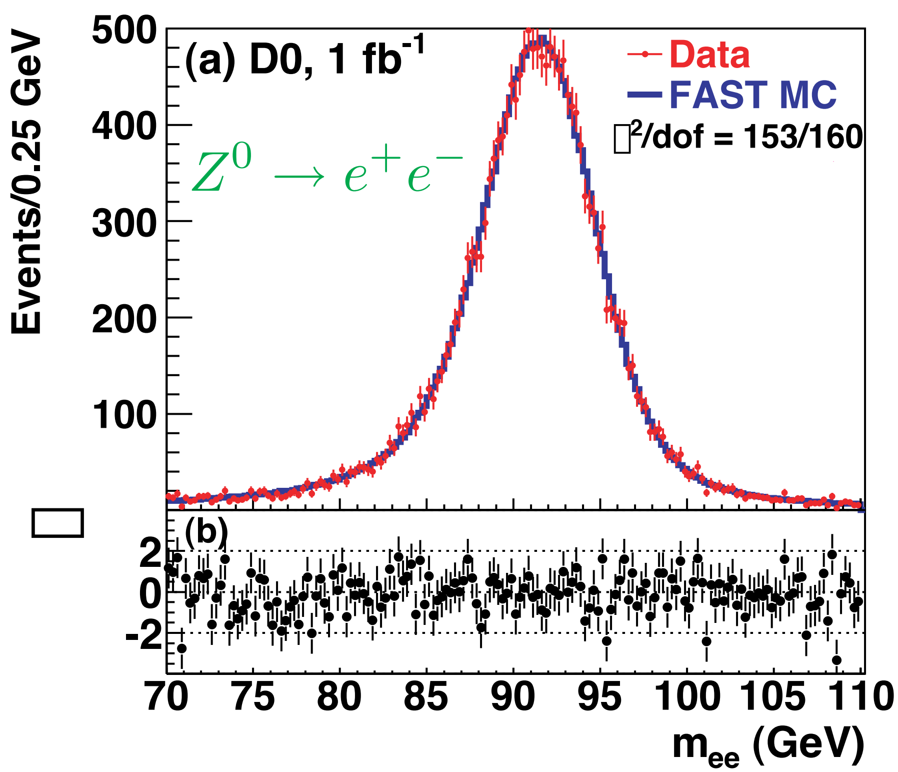
Electron energy resolution (□=0)

$\sigma_E/E = 3.6\%$ at 50 GeV



W Mass

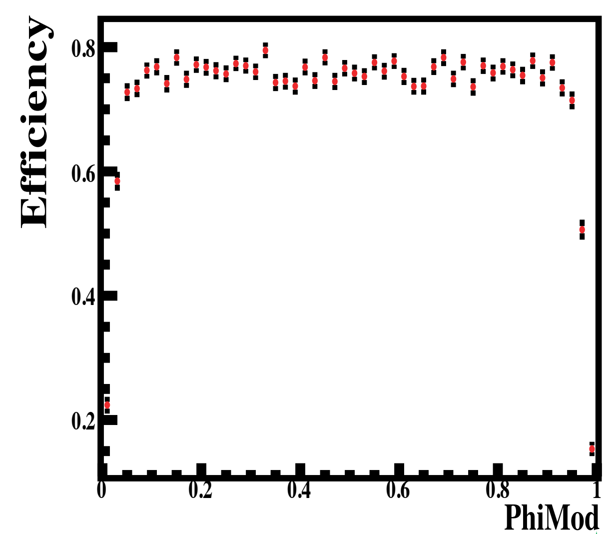
- To get required precision, need many samples with statistics of ~10^8
  Precludes full MC, plus *doesn't get the details right at this level of precision.*
- Tune parametric ("fast") simulation using both full simulation and data; ultimately $Z^0 \rightarrow e^+e^-$ data control events



$$M_Z = 91.185 \pm 0.033\,(\mathrm{stat})\,\mathrm{GeV}$$

cf. $M_Z(\mathrm{world\ average}) = 91.188\,\mathrm{GeV}$

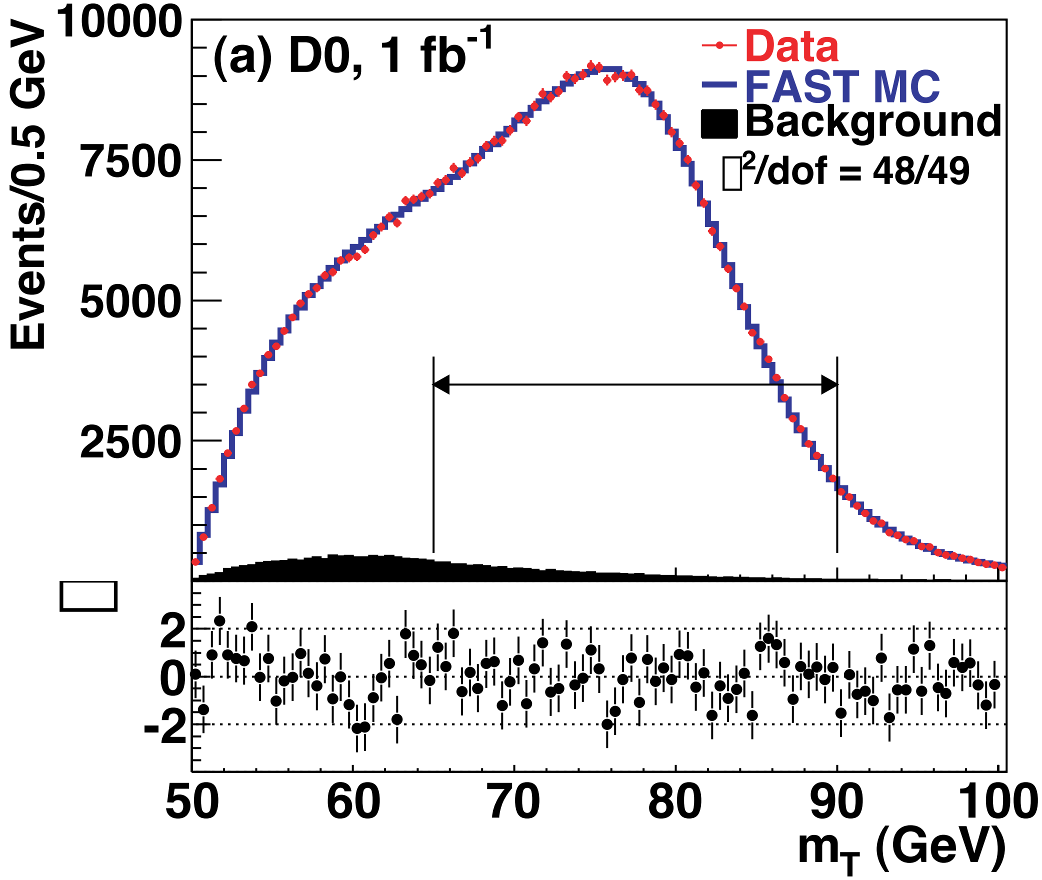
- Electromagnetic response and resolution in MC tuned using this sample (~400 templates, 50M events each)
- Only one of huge number of control plots



Few mm gaps between modules

W Mass

- Fit data to simulated distributions (templates in steps of $M(W)$ = 10 MeV) to determine mass



- Tested all methods with full MC simulation treated as data
- For data, blinded *W* mass value until control plots okay
- Also fit to p_T^e, $\not{E}_T$ and combine (not fully correlated!)

  The correlation coefficients are determined using ensembles of simulated events (other important use of MC).

W Mass

$$M_W = 80.401 \pm 0.021\,(\mathrm{stat}) \pm 0.038\,(\mathrm{syst})\ \mathrm{GeV}$$

- Most experimental systematic uncertainties limited by $Z^0 \rightarrow e^+e^-$ statistics; i.e., will improve with more data! (the importance of scales!)

TABLE II: Systematic uncertainties of the M_W measurement.

Source	M_W (MeV) m_T	p_T^e	$\not{E}_T$
Electron energy calibration	34	34	34
Electron resolution model	2	2	3
Electron shower modeling	4	6	7
Electron energy loss model	4	4	4
Hadronic recoil model	6	12	20
Electron e ciencies	5	6	5
Backgrounds	2	5	4
Experimental Subtotal	35	37	41
PDF	10	11	11
QED	7	7	9
Boson p_T	2	5	2
Production Subtotal	12	14	14
Total	37	40	43

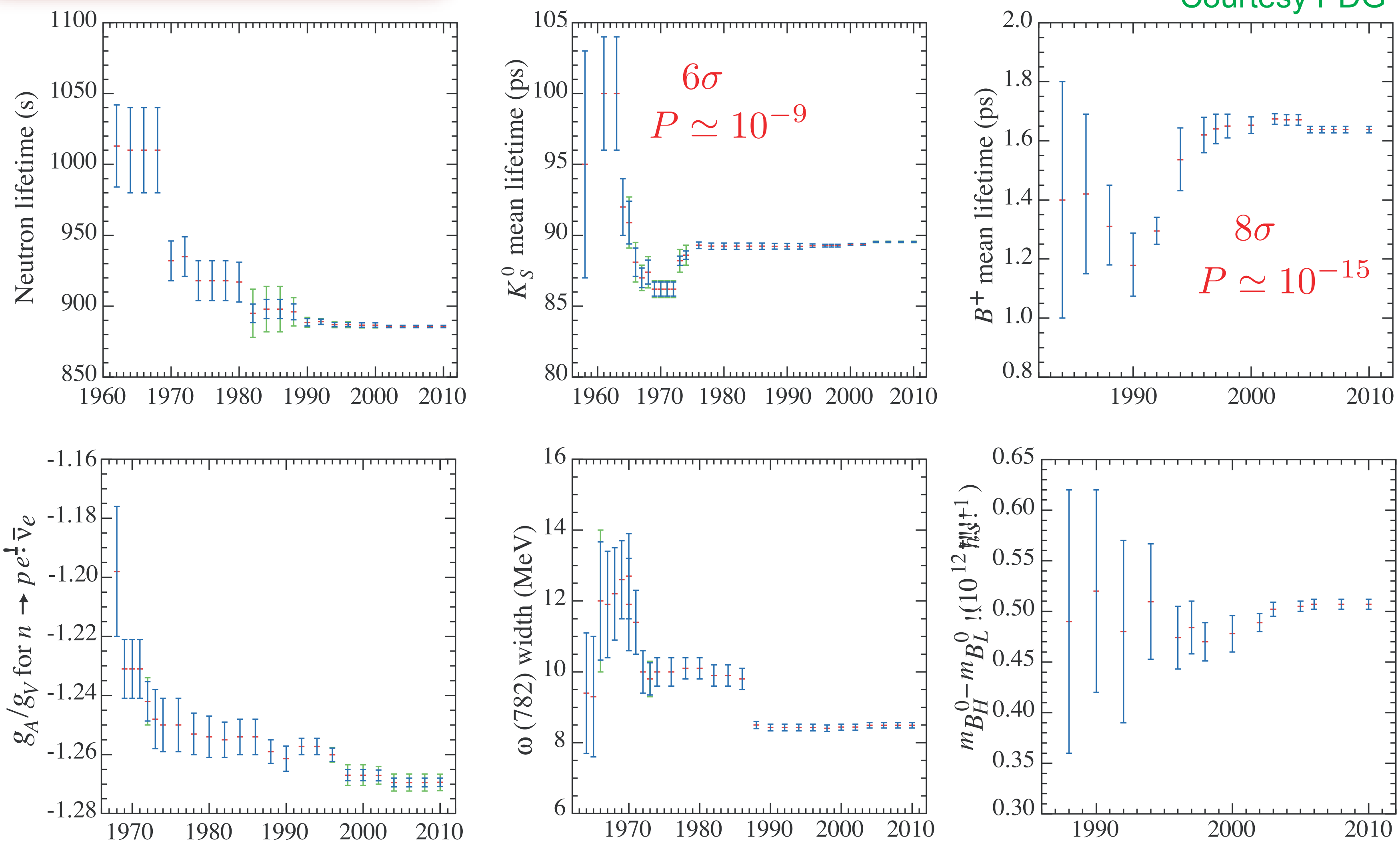
- 0.05% total precision: demonstrates what can be done working very hard with fundamentally straight-forward techniques ("fast" MC, templates)

(analysts should all receive "sub per mille medals")

Sobering...

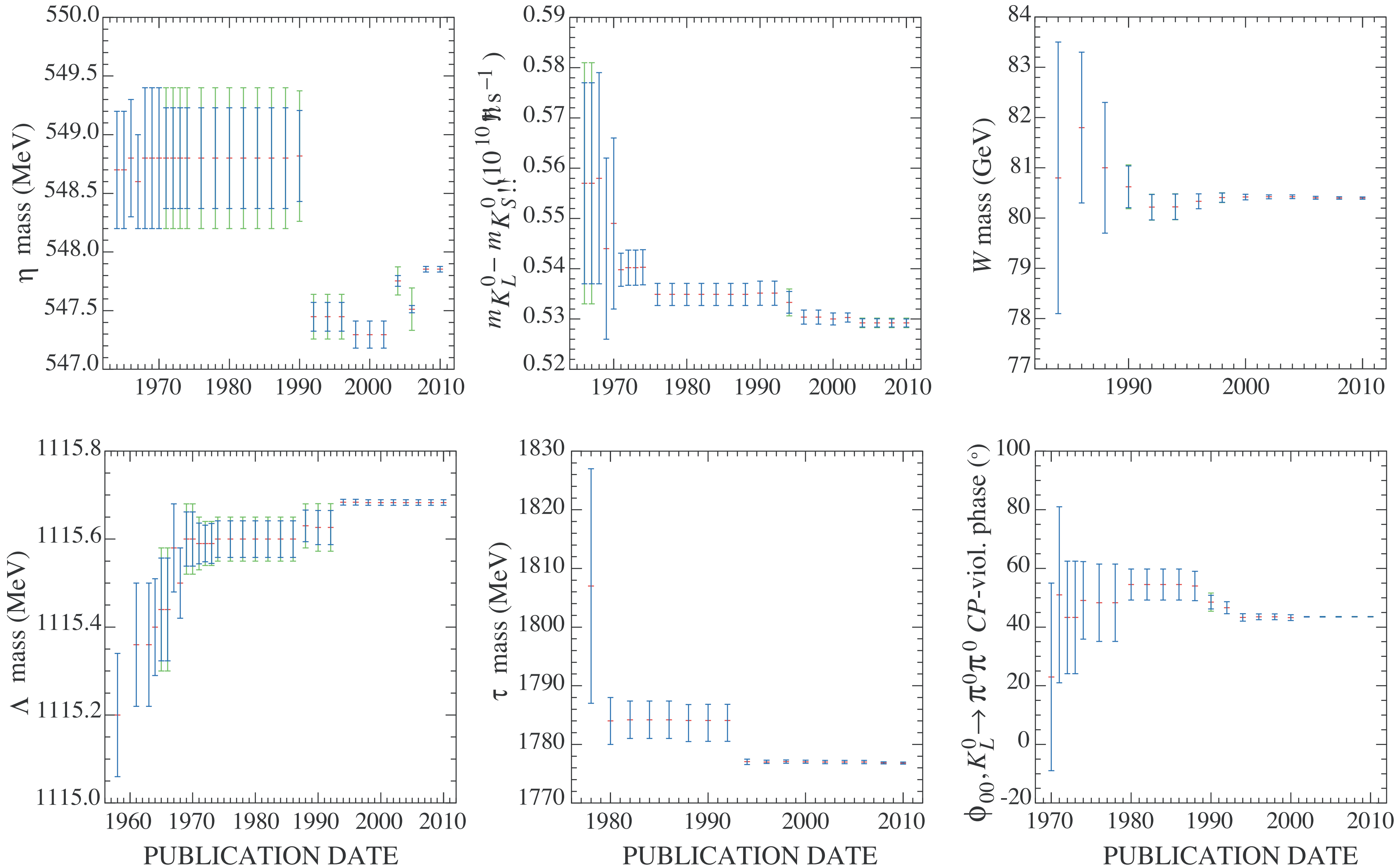
Particle physics' dirty little secret(s)

Courtesy PDG



Possible that the experimenters during a period paid too much attention to the level of agreement between their new result and the measurements of the recent past. If one judges whether a result is ready for publication by its agreement with the current world average, such disasters can happen!

...to be fair


η mass (MeV)
$m_{K_L^0} - m_{K_S^0}$ (10^{10} ħ s^{-1})
W mass (GeV)
Λ mass (MeV)
τ mass (MeV)
ϕ_{00}, $K_L^0 \to \pi^0\pi^0$ CP-viol. phase (°)
PUBLICATION DATE
PUBLICATION DATE
PUBLICATION DATE

Biases

Unbiased if the expectation value of the estimator
is equal to the true value: $E[\hat{a}] = a$

Biased, doesn't matter how much statistics $E[\hat{a}] = a + \underbrace{b}_{\text{bias}}$

If the bias vanishes for large N, then the estimator is asymptotically unbiased

If we have mere statistical bias, this is usually not a problem and can be corrected!!
Experimenter bias occurs when human behaviour enters the equation.

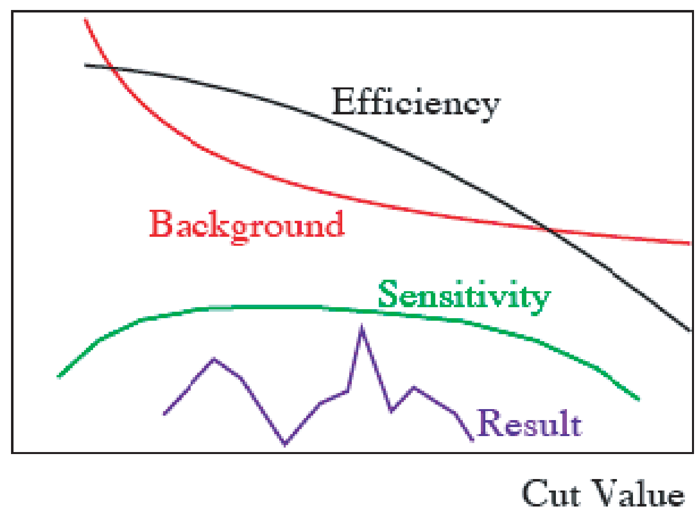
Biases

Typical Sources

Tuning on the data (a cardinal sin, particularly low stats)

- If you are not tuning on the data, why do you need to see the data, and what aspects do you need to see?
- e.g., making cut value choices within a reasonable range (e.g., plateau of sensitivity) but with a knowledge of the data

  A signal inside of 2500 events. Make 10 cuts, each 90% efficient, but 1% bias in each (i.e., upward fluctuation). Results in a 3σ effect in the resulting signal



Stopping when the data “looks right”

- A priori there is no inherent termination point of an analysis … try to set milestones before starting (easier said than done)

Biases

Typical Sources

- Looking for bugs when a result does not conform to expectation (and not looking when it does)
- Looking for additional sources of systematic uncertainty when a result does not conform
- Deciding whether to publish, or to wait for more data
- Choosing to drop "outliers" or “strange” events
- The data selection criteria are unconsciously adjusted to bring the answer closer to a theoretical value or a previously measured value.
- Comprehensive checks are performed if the answer disagrees with expectation, otherwise not so comprehensive. The extra checks might be invented by the analysts, or requested by convenors, editorial/review boardss, etc.
  (The experimenters feel more confident when the answer comes out “right”. These checks may lead to “corrections” that change the answer)
- Several competing analyses are performed using the same data. The responsibles charged with making the decision chooses which is worthy of publication after learning the answers, unconsciously favouring analyses that “come out right”.

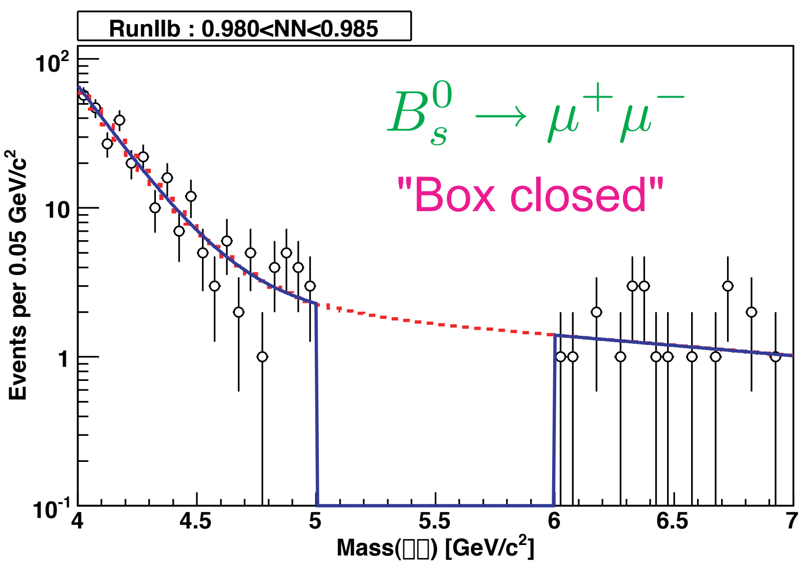
Biases

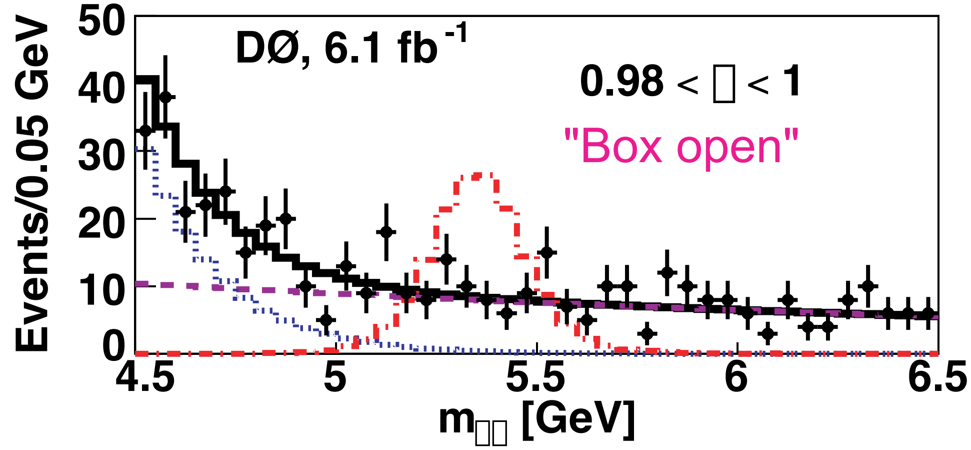
In each case, the experimenter bias is unintentional – the experimenters normally know that these practices are objectionable, but in each example, the course of the analysis is unconsciously influenced by their knowledge of how the outcome is affected

Blind Analysis

Know pitfalls and do best to avoid, or...

Hide the number of events (or don't look) in the signal region (i.e., the box) until the cuts have been finalized, the acceptance has been determined (with possible backgrounds estimated).
At the final stage, the box is opened, and the answer (cross section measurement or limit) is computed.





Estimate background in blinded region by extrapolating from sidebands (for a certain neural net output bin)

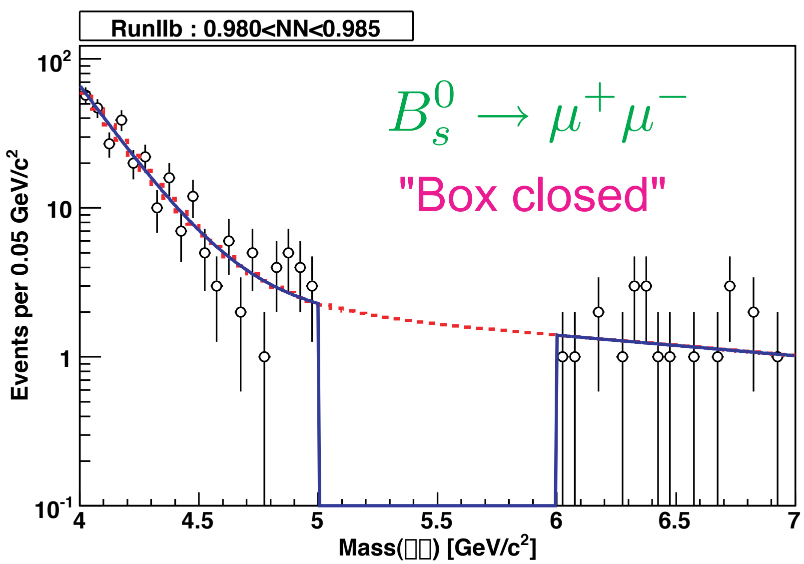
A priori decide on criteria/tests:

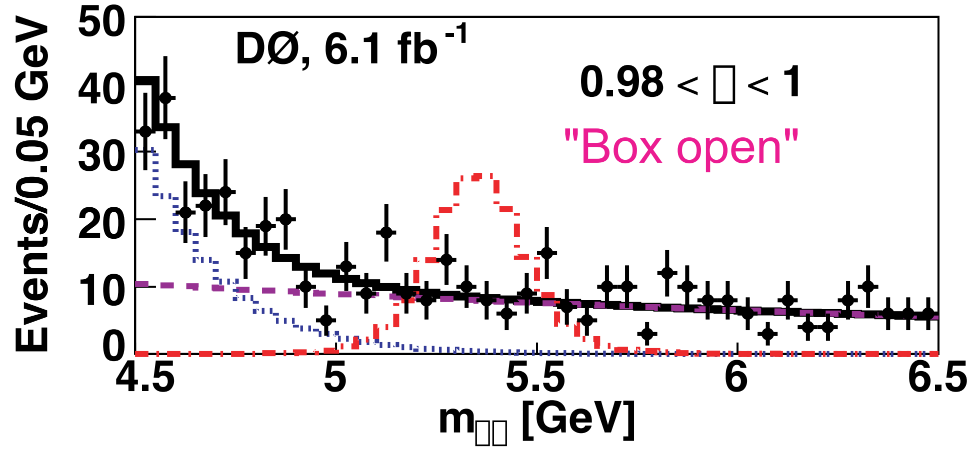
- For when to open box
- "Sanity" checks once box opened

Blind Analysis

Know pitfalls and do best to avoid, or...

Again, be "trigger aware", e.g., this one focusing on dimuon triggers significantly biased or "sculpted" the muon p_T spectrum, needing correction





Estimate background in blinded region by extrapolating from sidebands (for a certain neural net output bin)

A priori decide on criteria/tests:

- For when to open box
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Blind Analysis

Know pitfalls and do best to avoid, or...

Shifting the answer ("Opening box" = revealing/removing shift) [exciting...]

- In some cases, it may be sufficient to shift the answer by adding a random (but fixed and unknown) offset to the answer.
- An advantage of this approach is that it allows two independent groups to analyze the same real data and compare their answers—both having the same random offset

e.g., KTeV:

$$\epsilon'/\epsilon\,(\mathrm{Hidden}) = \left\{ \begin{array}{c} 1 \\ -1 \end{array} \right\} \times \epsilon'/\epsilon + C$$

Shift constant C unknown, also +1 or –1 unknown (prevented KTeV from knowing which direction the result moved as changes were made)

(Similar for BaBar for sin2)

e.g., $B_d^0 - \bar{B}_d^0$, $B_s^0 - \bar{B}_s^0$ oscillations. Randomize sign of flavor tag (B^0 or $\bar{B}^0$?). Should result in a null result (or apply to another system that should give a null result...)

Blind Analysis

Hiding (some) of the data!

- Might randomly split all data event-by-event into two sets: A and B.
  The analysis procedure is developed using set A – set B is not looked at all.
  Once the analysis algorithm is finalised, if, say, systematics limited,
  set A is discarded, and the analysis is run on set B, which determines the final answer (or used as an important control/confirmation check).
  (not always free of biases, e.g., calibration in A being used in B)

- Method seems suited to a case where many cut variations are tried on data in order to search for unanticipated signals (bump hunting being a prime example), but the analysis procedure is otherwise fixed.
  Since it is easy to be fooled by the statistical fluctuations that mimic new effects – if enough cut variations are investigated. In such cases, it is helpful to have the unexplored set B to confirm or refute any "discovery" in set A (or simply take more data...)

The fundamental strategy is to avoid knowing the answer until the analysis procedure has been set. Since checks may lead to a change (or correction) of the procedure, they should be completed, or at least scheduled, before the answer is revealed.

Searches

First looking for a significant excess above background

(see stat. tools, Barlow's talk)

- Minimize background and/or know them very well
- Efficiency: retain as much of the new particle signal as possible; more important is signal/background separation.

As long as reasonably high, *value* itself is not important/needed until setting the limit, and then we are back to:

Number of observed candidates
(fitted or counted)

Number of background candidates
(measured from data
or calculated from theory)
(minimize)

Cross section in cm^2
(or □b, nb, pb)

$$\sigma = \frac{N_{\mathrm{obs}} - N_{\mathrm{backg}}}{\epsilon \cdot \int \mathcal{L} dt}$$

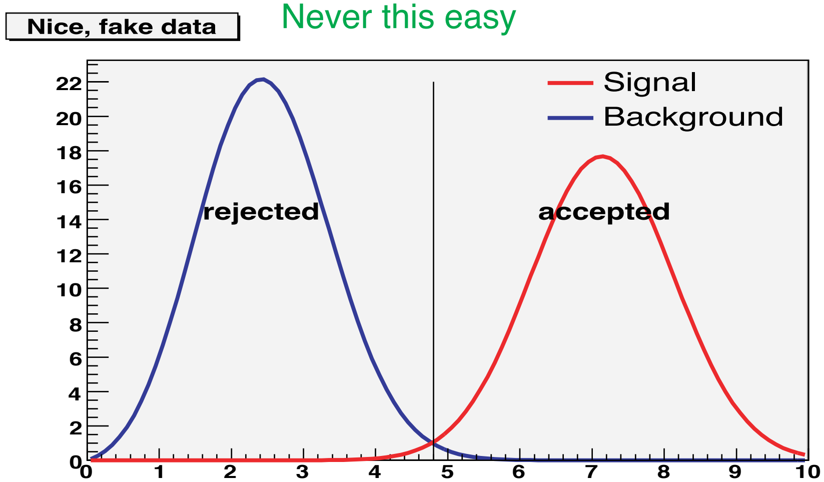
Efficiency/acceptance
(maximize)

Integrated Luminosity in cm^{-1}
(or $□b^{-1}$, nb^{-1}, pb^{-1})
(maximize,
unless systematically limited)

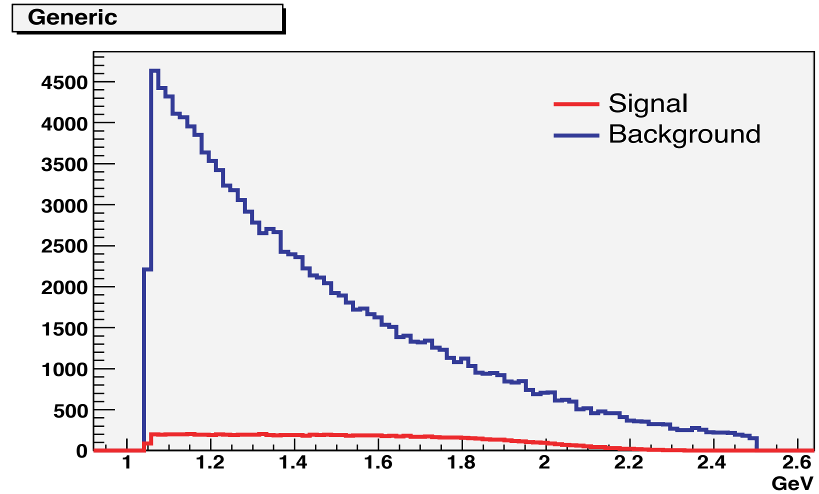
Event Selection

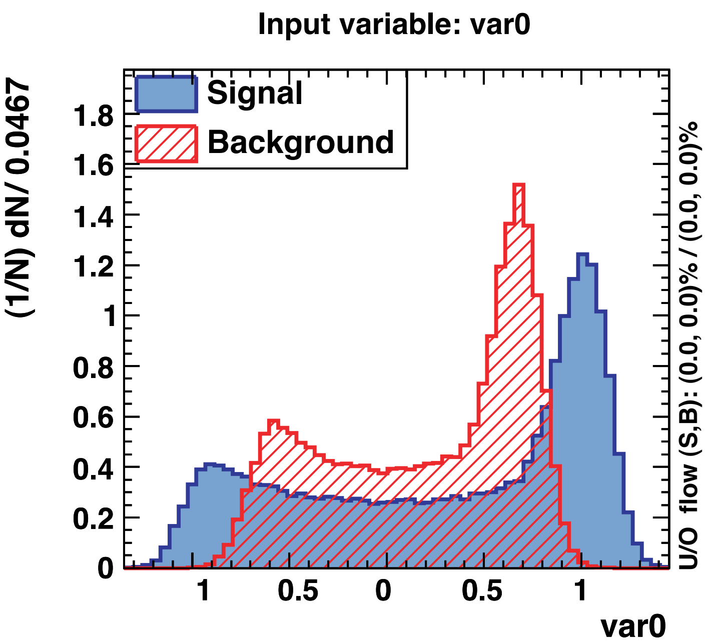
"*Separating with variables*"

Never this easy

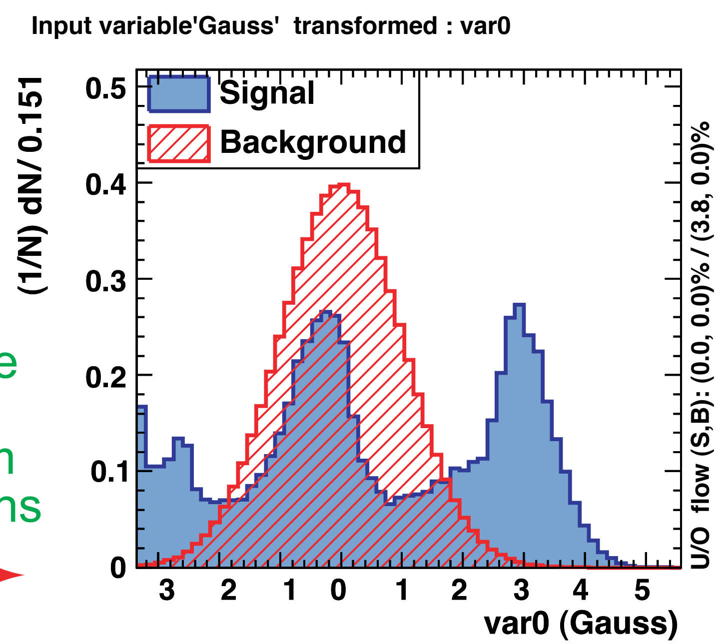


Divide the data in a nice way. No Such Variable!





There are ways to transform distributions



https://tmva.sourceforge.net/

Multivariate Techniques

Likelihood Discriminants

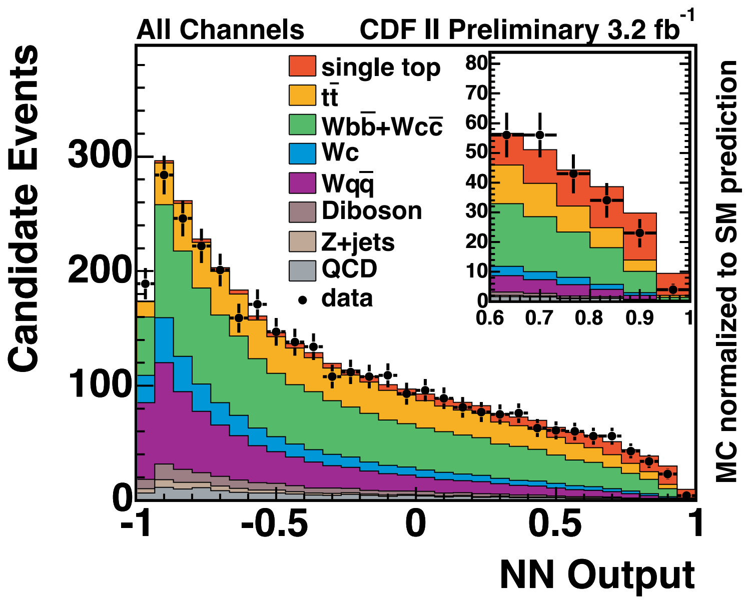
Best you can do if no correlations

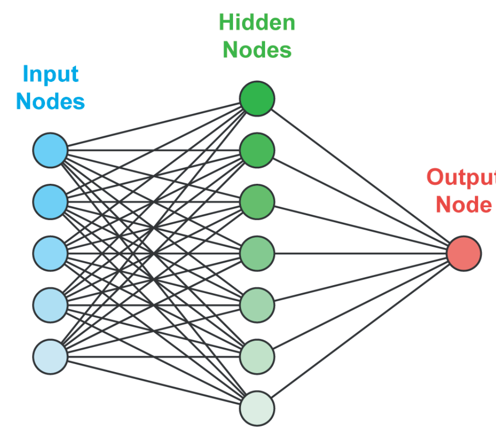
$$L(\vec{x}) = \frac{P_{\text{sig}}(\vec{x})}{P_{\text{sig}}(\vec{x}) + P_{\text{bkg}}(\vec{x})} \qquad P_{\text{sig}}(\vec{x}) = P_{\text{sig}}(x_1)P_{\text{sig}}(x_2)P_{\text{sig}}(x_3, x_4)...$$

e.g., histo
of variable

Not best that one can do if there are non-linear correlations

Artificial Neural Networks





Develops ("learns") non-linear selection criteria on combinations of variables

Discriminate between S & B when you have many, correlated variables, none of which individually give clear separation

Trained with samples of "signal" and "background"

Samples repeatedly presented to network

Outcome compared with desired

Link strengths adjusted

Multivariate Techniques

Likelihood Discriminants

Best you can do if no correlations

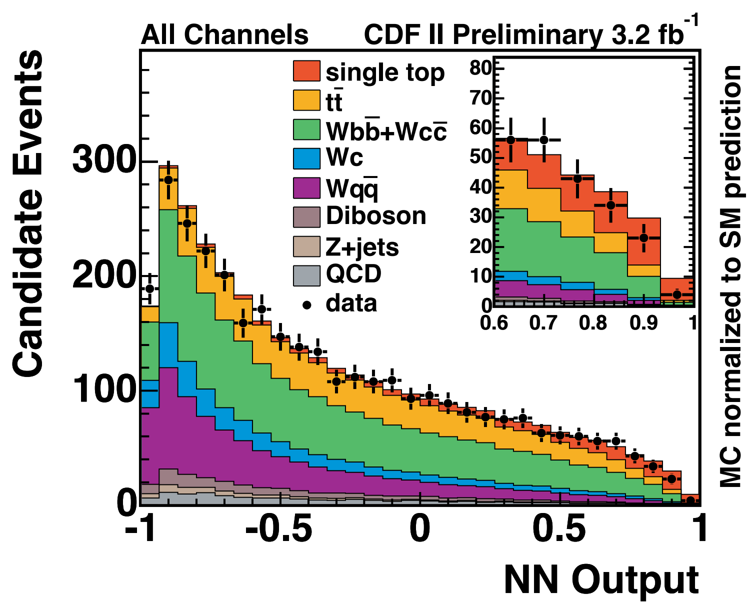
$$L(\vec{x}) = \frac{P_{\rm sig}(\vec{x})}{P_{\rm sig}(\vec{x}) + P_{\rm bkg}(\vec{x})}$$

$$P_{\rm sig}(\vec{x}) = P_{\rm sig}(x_1)P_{\rm sig}(x_2)P_{\rm sig}(x_3, x_4)...$$

e.g., histo
of variable

Not best that one can do if there are non-linear correlations

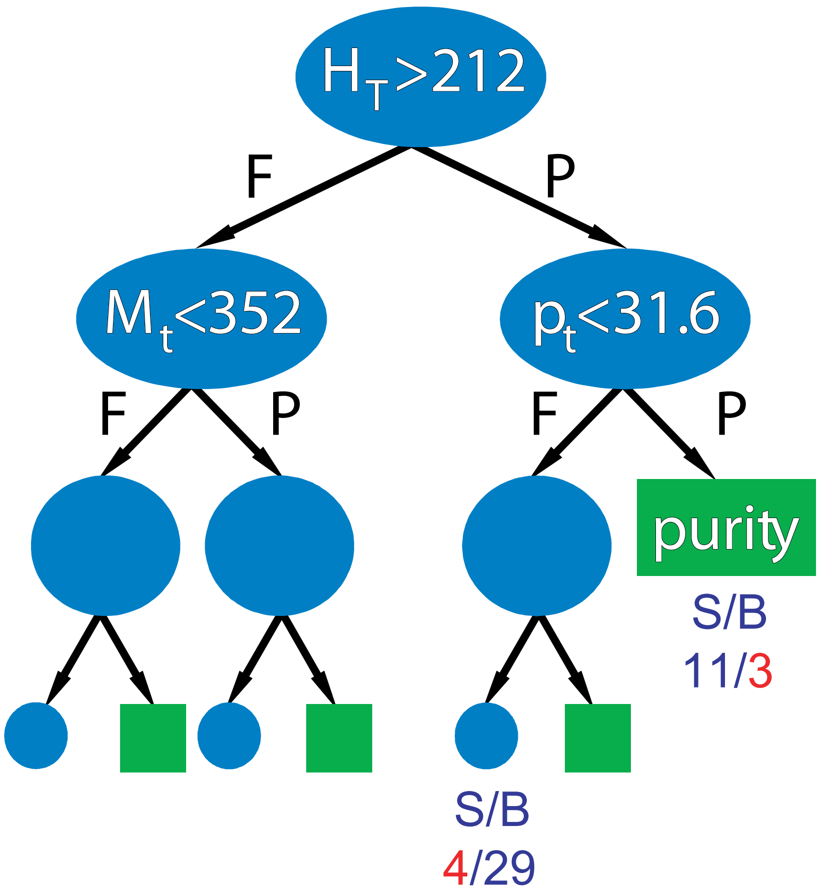
Artificial Neural Networks



Single top outstanding
test bed for preparing
for searches: small signal
requiring advanced techniques
in presence of large backrounds

Multivariate Techniques

Decision Trees



Optimally split data recursively until at each node until a stopping criterion is reached (e.g., purity or too few events)

All events end up in either a "signal" or a "background" leaf

"Boosted" or "bagged" decision trees

Many more...

Multivariate Techniques

○ Bad
⋆ Fair
⋆⋆ Good

Criteria		Cuts	Likelihood	Prob. Density Est. Range Search	Prob. Density Est. Foam	H-Matrix	Fisher/Liear Disc.	Artificial Neural Net	Boosted Decision Tree	Rule Ensembles	Support Vector Machies
Perfor-mance	No or linear correlations	⋆	⋆⋆	⋆	⋆	⋆	⋆⋆	⋆⋆	⋆	⋆⋆	⋆
	Nonlinear correlations	○	○	⋆⋆	⋆⋆	○	○	⋆⋆	⋆⋆	⋆⋆	⋆⋆
Speed	Training	○	⋆⋆	⋆⋆	⋆⋆	⋆⋆	⋆⋆	⋆	○	⋆	○
	Response	⋆⋆	⋆⋆	○	⋆	⋆⋆	⋆⋆	⋆⋆	⋆	⋆⋆	⋆
Robust-ness	Overtraining	⋆⋆	⋆	⋆	⋆	⋆⋆	⋆⋆	⋆	○	⋆	⋆⋆
	Weak variables	⋆⋆	⋆	○	○	⋆⋆	⋆⋆	⋆	⋆⋆	⋆	⋆
Curse of dimensionality		○	⋆⋆	○	○	⋆⋆	⋆⋆	⋆	⋆	⋆	○
Transparency		⋆⋆	⋆⋆	⋆	⋆	⋆⋆	⋆⋆	○	○	○	○
Regression (# Targets)		no	1	N	N		1	N	1		1

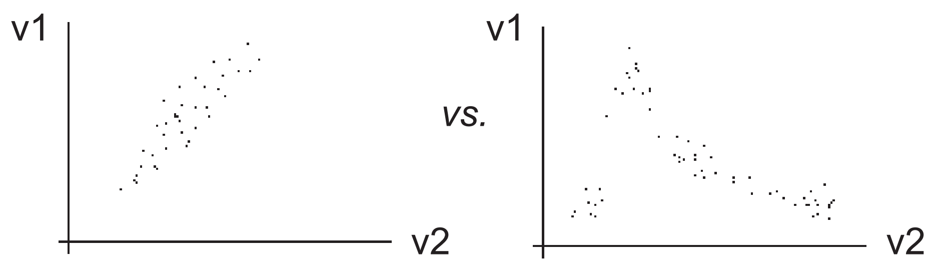
TMVA: The toolkit for multivariate data analysis, (Preprint arXiv:physics/0703039)
https://tmva.sourceforge.net/

Multivariate Techniques

- Weak variables refers to variables with no or only a small discrimination power.
- Curse of dimensionality refers to the “burden” of required increase in training statistics and processing time when adding more input variables.
- Transparency: how much of black box?
- If the method can be used for regression analysis, the number of targets is given which can be trained simultanously in one analysis, e.g., can have two outputs, one for *b*-jets, other for *c*-jets

Bottom-line

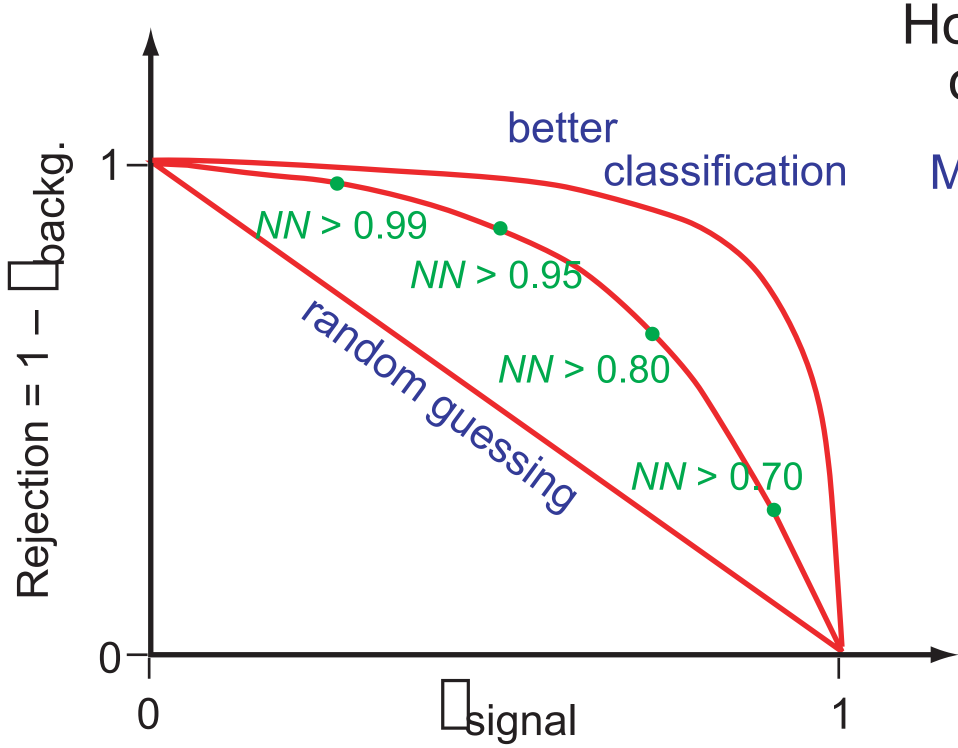
- Check the correlations between selection variables. If important ones have non-linear correlations, can potentially benefit from one of the advanced techniques



- Tool will then be taking advantage of the correlations, does the MC used for training get it right? Is the tool picking up some artifact in the MC?
- May take longer to assign an efficiency and syst. uncertainty (e.g., data/MC comparisons, changing the training distributions)

Multivariate Techniques

Choose a "working point" by sliding along the curve with a given single discriminator cut



How to choose? Depends on analysis! (also for square cuts)

Maximize Figure of Merit (FOM): π = purity

- $\dfrac{S}{\sqrt{S+B}}$ Have signal, measure property
- $\dfrac{S}{S+B}$ High purity for precision
- $\epsilon\pi$ Only if know background very well
- $2\pi(1-\pi)$ Givin index (dec. tree)
- $\dfrac{S}{\sqrt{B}}$ Searching for signal
- $\dfrac{S}{\alpha/2+\sqrt{B}}$ "Punzi": searching for signal, exclude or discover at α sigma

Background e.g., in Data: "*Matrix Method*"

Saw previous example in top analysis of calibrating normalization of background of W+jets in background enhanced region, extrapolating to signal region.

Another useful (general!) data-driven way to find a background, e.g., isolated lepton fake rate (both from mismeasurements as well as real non-isolated leptons) "instrumental"

want

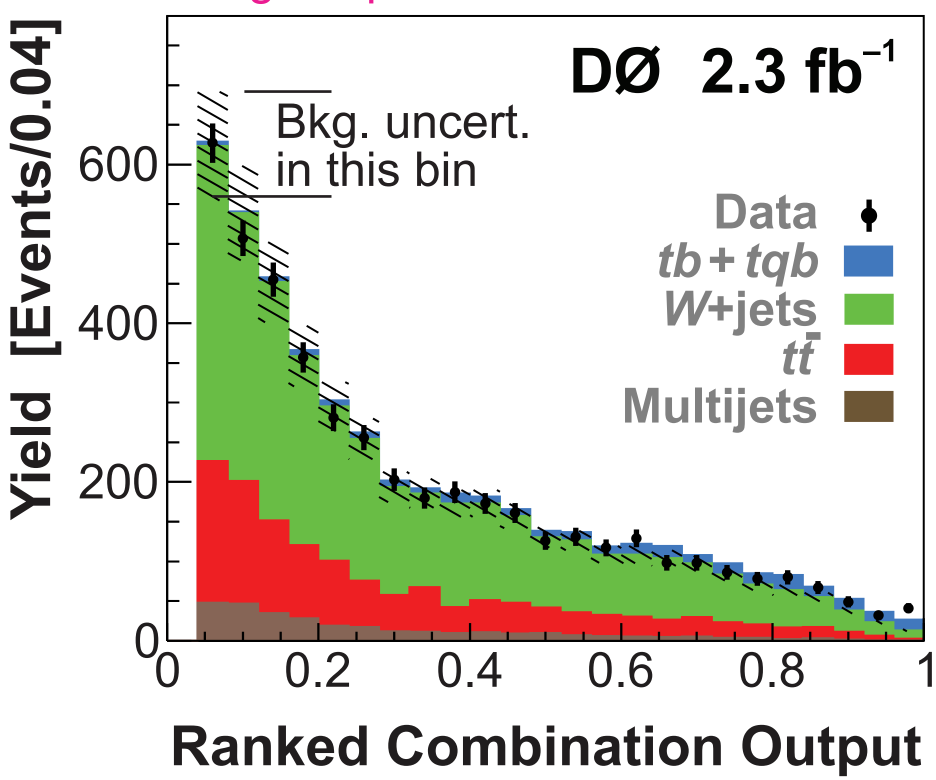
After selection cut(s): $$N^{\rm tight} = \boxed{N^{\rm tight}_{\rm QCD}} + N^{\rm tight}_{\rm sig}$$

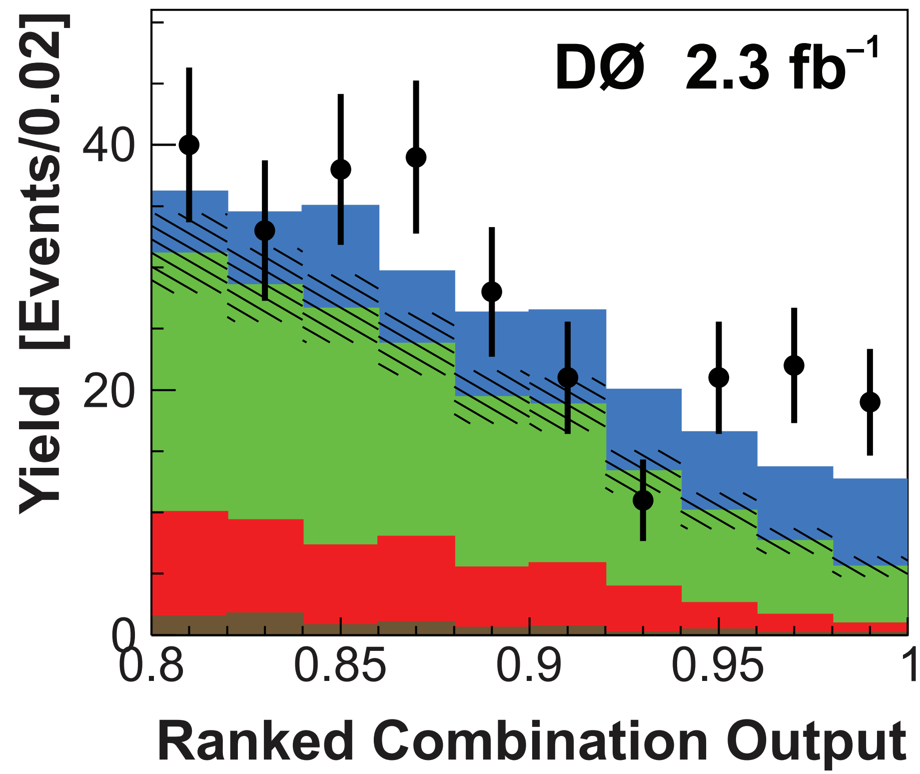
- Start with loose sample: $N^{\rm loose} = N^{\rm loose}_{\rm QCD} + N^{\rm loose}_{\rm sig}$
- Apply selection cut(s): $N^{\rm tight} = \epsilon_{\rm QCD} N^{\rm loose}_{\rm QCD} + \epsilon_{\rm sig} N^{\rm loose}_{\rm sig}$
- Find $\epsilon_{\rm QCD}$ by applying selection cut(s) to a separate background-enhanced sample, e.g., inverting a cut: "loose but not tight" (e.g., non-isolated)
- Find $\epsilon_{\rm sig}$ from MC (with appropriate corrections)
- Solve the equations for the unknowns

Backgrounds

- Use data in background-enhanced region to constrain normalization of backgrounds, extrapolate into signal region
- Despite this, will still have an additional theory error from shape prediction, e.g., for top, single top, particularly $W+$ n-jets as a dominant background (ALPGEN, Sherpa generators)

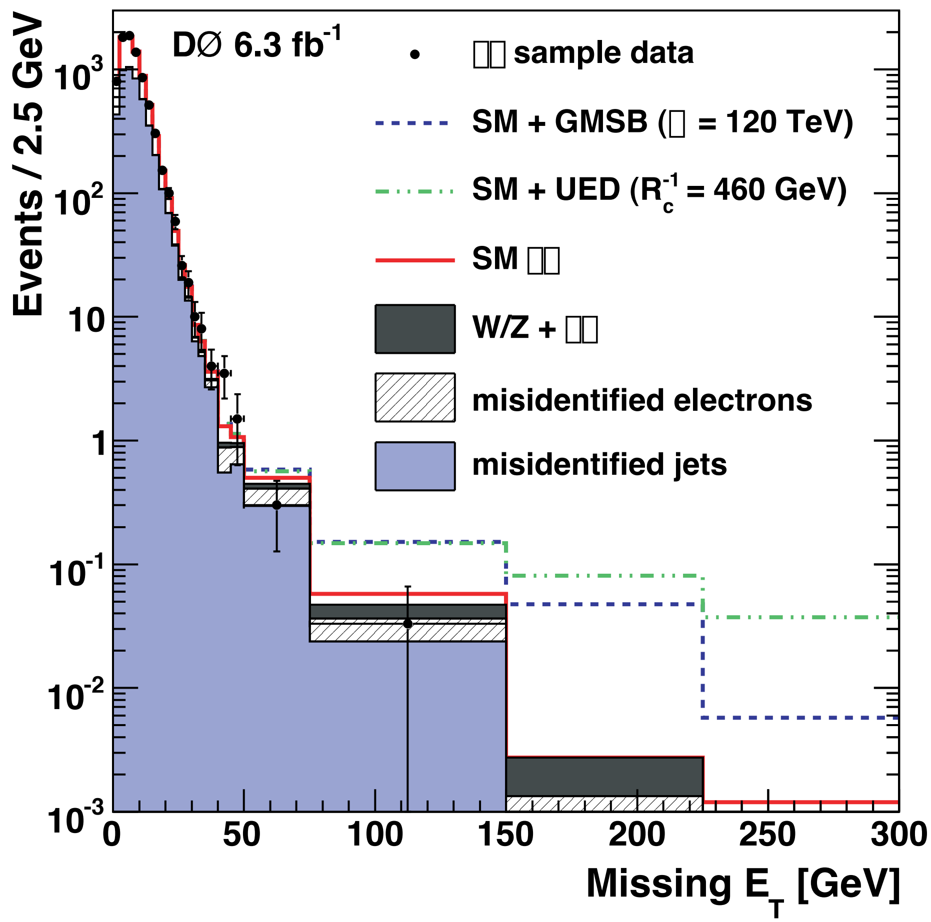
Single top





Backgrounds

Critical for searches: calibrated and stable missing E_T

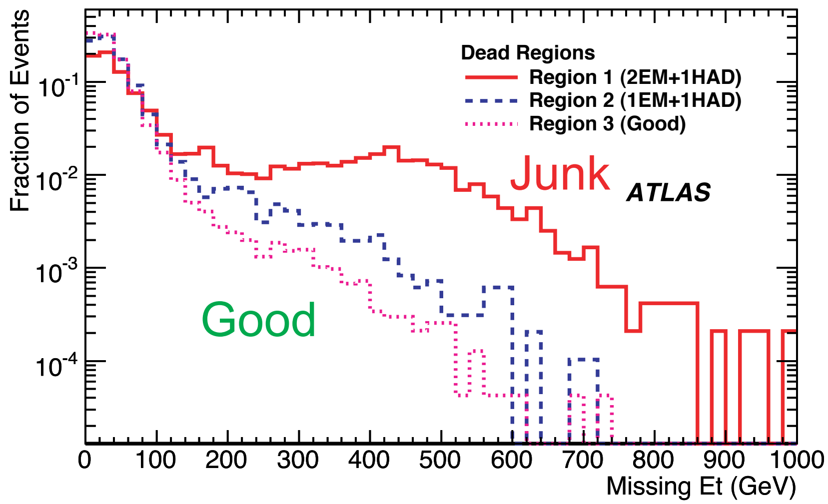


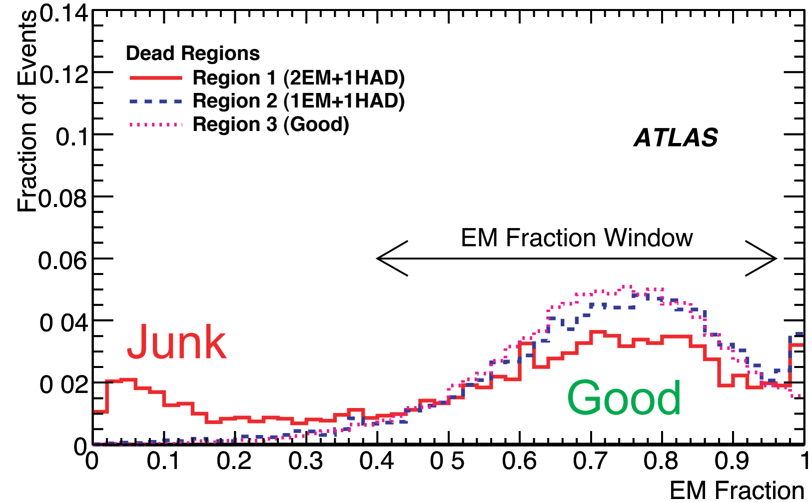
Beat on instrumental noise, much of which shows up in missing E_T

- Calorimeter (coherent) noise
  - Localized, firing in consecutive events, hot cells → Remove
- Dead regions
  - Calorimeter hardware problems,
    - Data quality cuts
- Cosmics & Hall background
  - Can overlap with min. bias events
    - Timing & pattern in calorimeters; track activity

Backgrounds

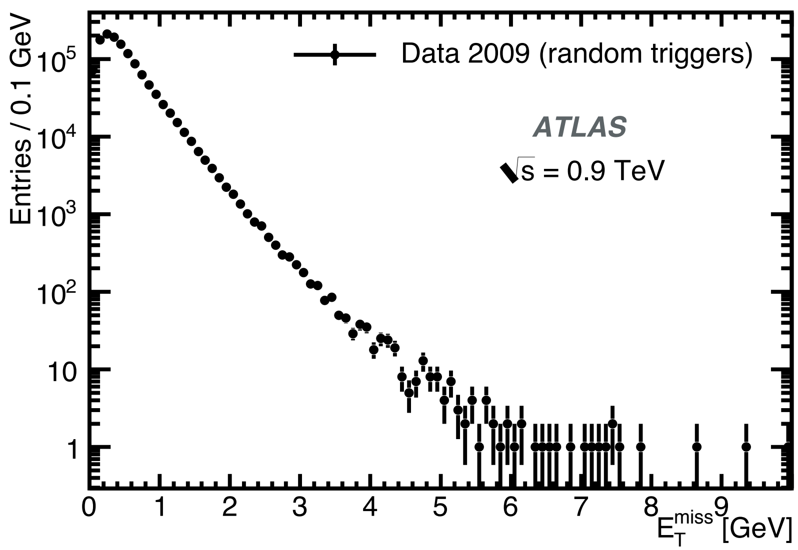
- Toss "bad jets", e.g., pattern of energy deposit not consistent:



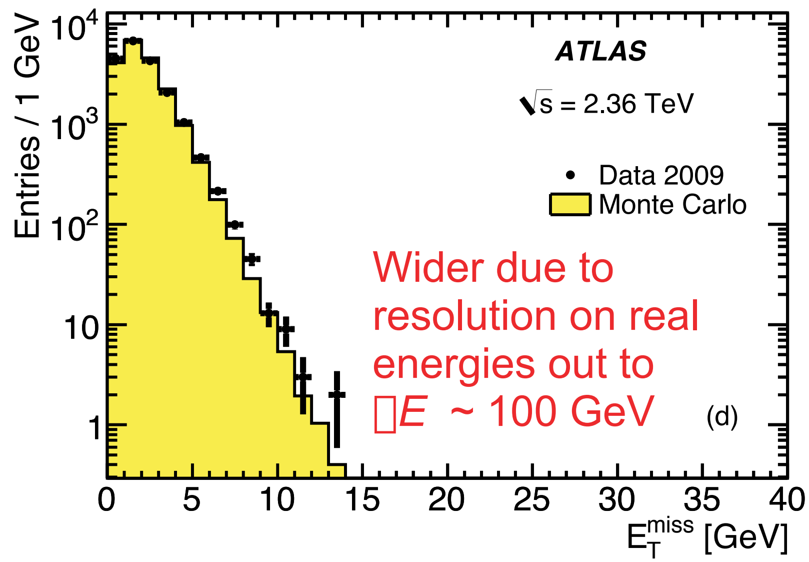


- Monitor

Zero-bias (random) triggers

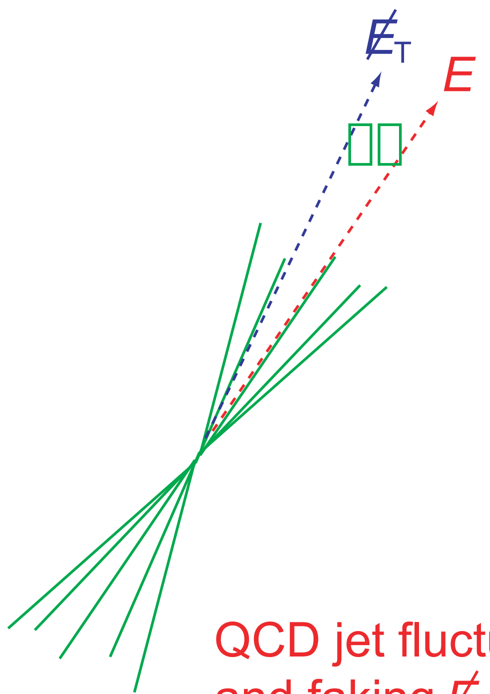


Minimum-bias triggers

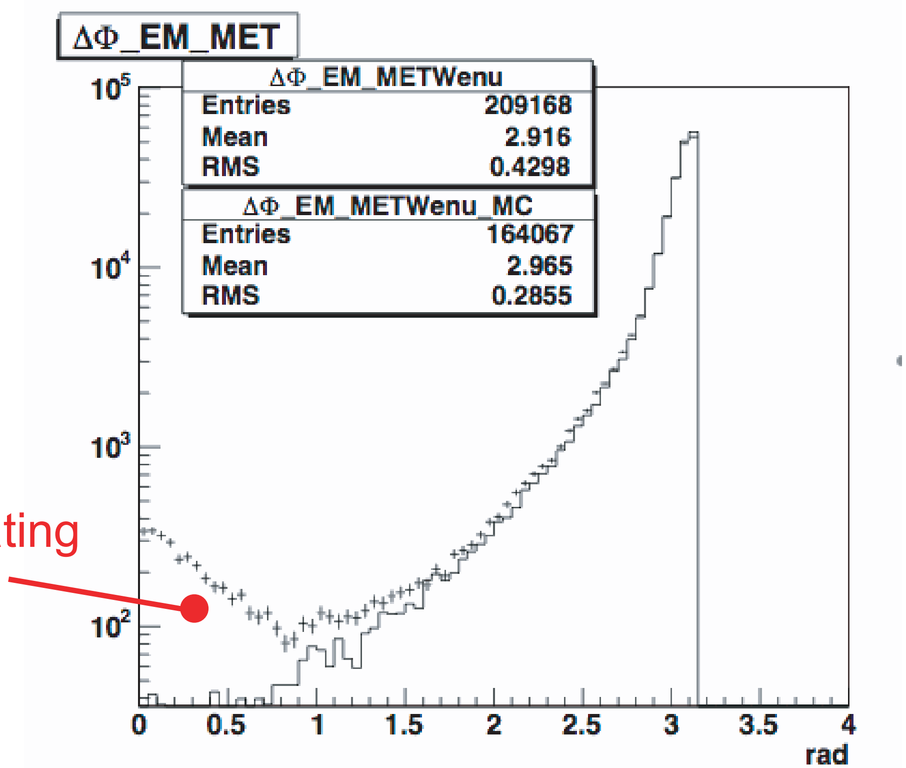


Backgrounds

- In data: pointing direction of missing E_T



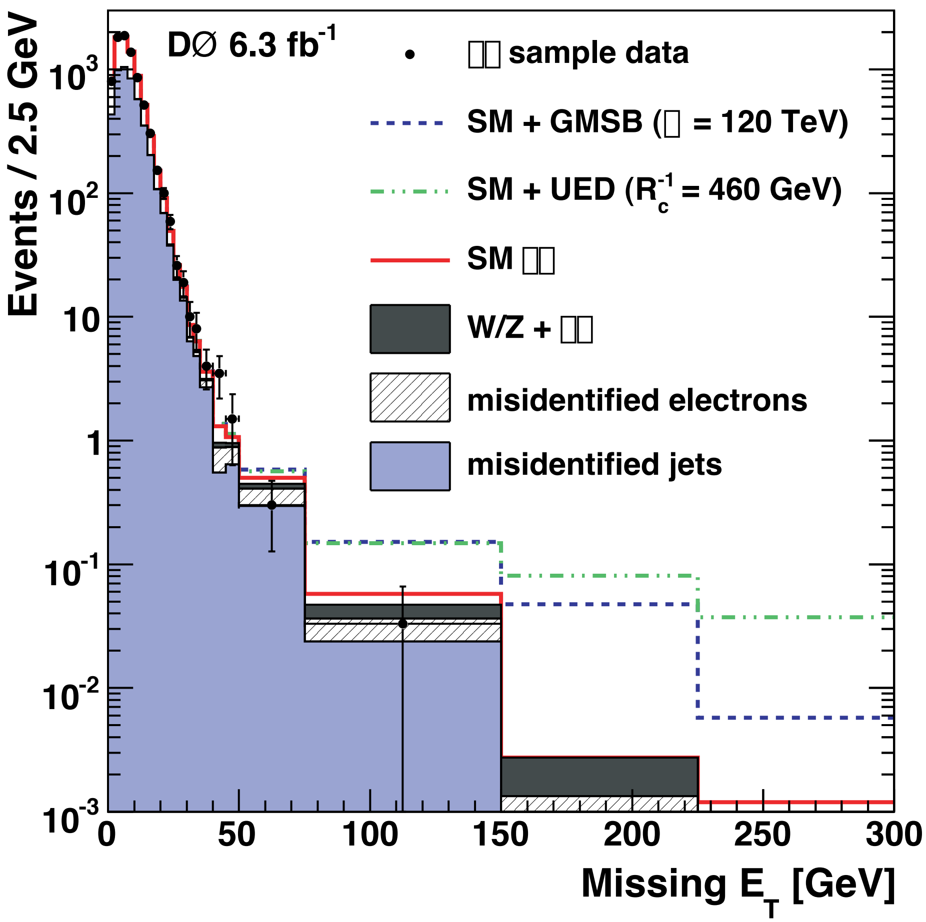
$$W \to e\nu$$



QCD jet fluctuating and faking $\not\!\!E_T$

Limit

Compare observed number of events to number from expected background



Statistics tools → Significant excess → Nobel? (bias?)

Statistics tools → Consistent → Set limit

- N.B.: as long as not an anomalous/ pathological situation, e.g., observed no. events significantly *less* than expected/predicted SM bkg.

→ Bayesian, frequentist, hybrid CL_s , how to fold in uncertainties, etc. should all give similar results!

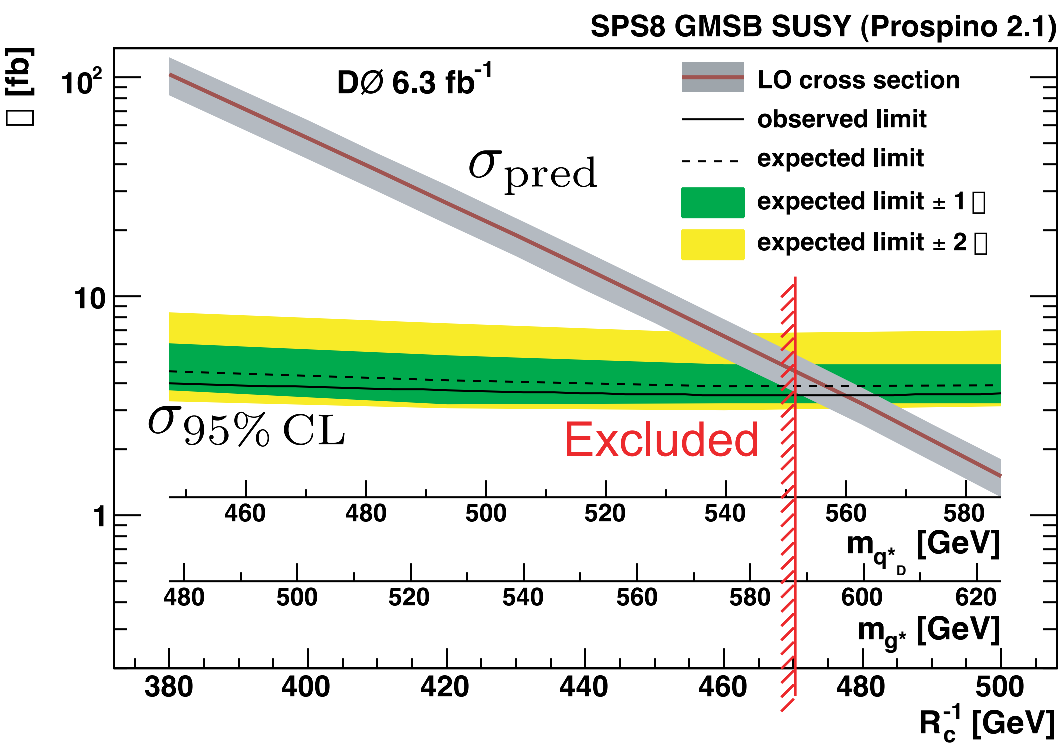
Problem? Ruling out the SM with your analysis?

Limit

Easy to remember, toy example, if backgrounds negligible:

N_{obs}	$N_{95\%\ CL}$
0	3.0
1	4.7
2	6.3

As a function of mass (usually), find $\epsilon \pm \Delta\epsilon$ and $\int \mathcal{L} dt$ to find observed $\sigma_{95\%\ \mathrm{CL}}$



- Favorite theory?

  $(m_0, m_{1/2})$ → mass, kinematics; σ_{pred}, *Br*

- Model-independent searches, e.g., *Quaero, Sleuth, Sherlock;* or publish N(obs), effic., backg., etc. curves

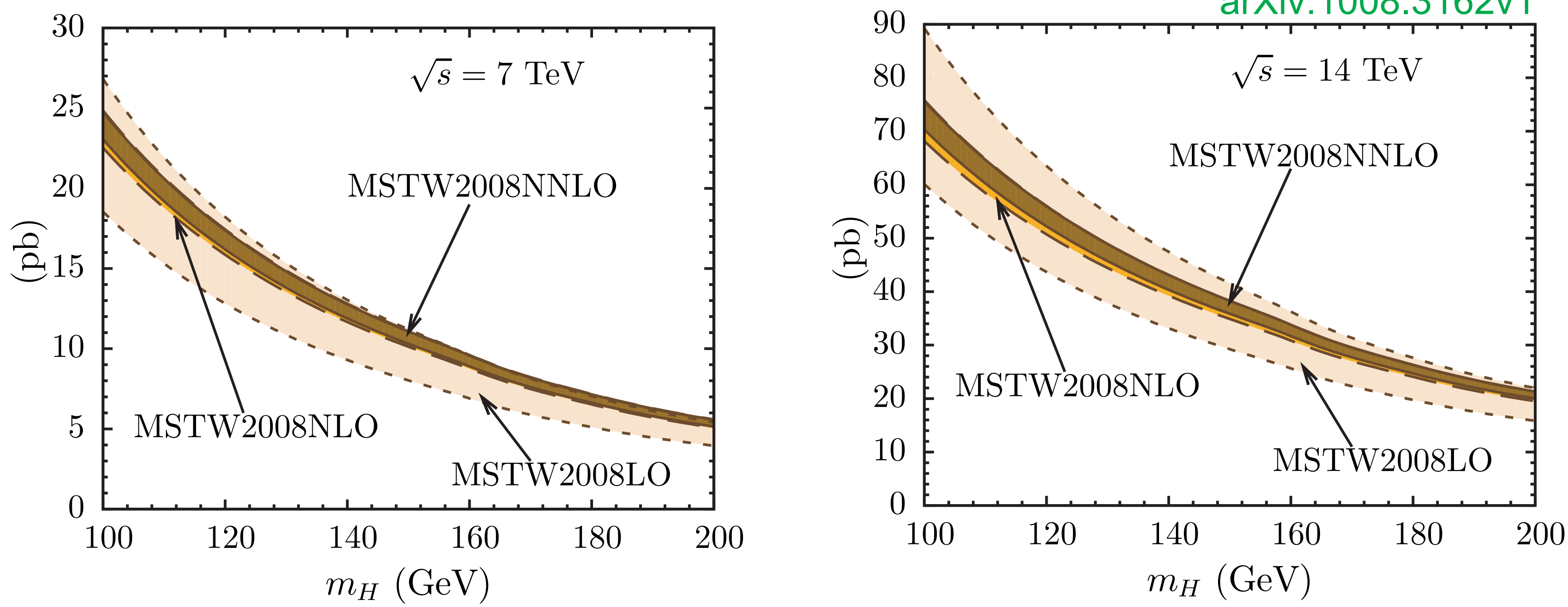
- Performance of search based on *expected* limit, observed limit will fluctuate

  (set observed bkg. to expected w/ uncertainty, or toy MC's)

Limit

...and as usual, have to worry about PDF's for theory prediction

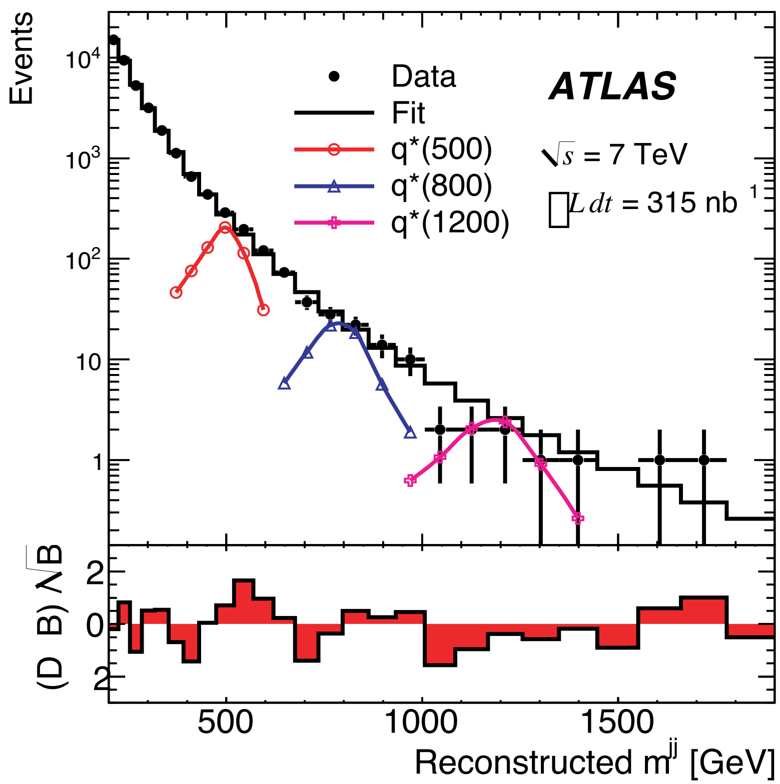
arXiv:1008.3162v1

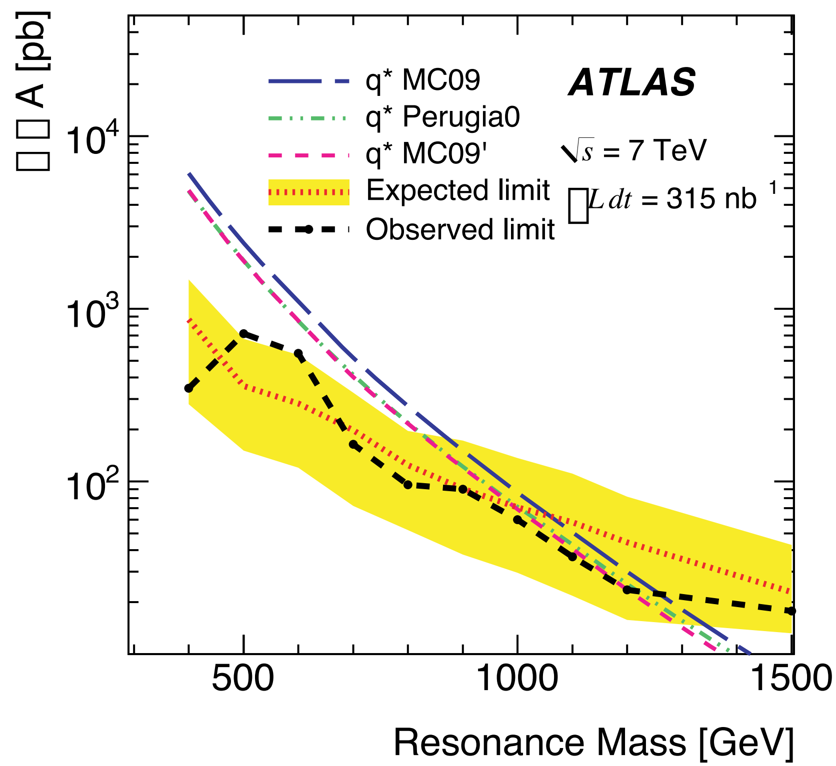


Limit

...and first limits already coming out of LHC...

Dijets, submitted to PRL





...now better limit than Tevatron

Systematic Uncertainties

Far from an exact science!

Distinguish systematic uncertainties from known and from unsuspected sources

Known sources:

- Errors on factors in the analysis: calibration, efficiencies, corrections, migrations, binning, …
- Theoretical uncertainties on branching ratios, masses, fragmentation, etc.
- Evaluate systematic uncertainties from known source s on correction factor F:

  Either take several (better many) typical assumptions for s_i and repeat calculation of F, then calculate standard deviation of F, potentially use a toy-MC

  Be honest: not over conservative or over aggressive.
  It is supposed to be ±1s, i.e,. 68% CL, whereas we often think of it as "worst case" to cover ourselves. Everyone will combine it in quadrature...
  Say what you did and how it was estimated.

  Vary expt.variables (E-resolution, tracking errors, …) and consider change in measurement variable (such as cross section)

Systematic Uncertainties

Uncertainties from unsuspected sources need first to be identified, *cross checks*:

- Repeating the analysis in different form helps to find systematic effects

  Vary the range of data used for extraction of the result, use subset of data, split the data independently in both educated and blind ways – check for impossibilities (phase of the moon?)

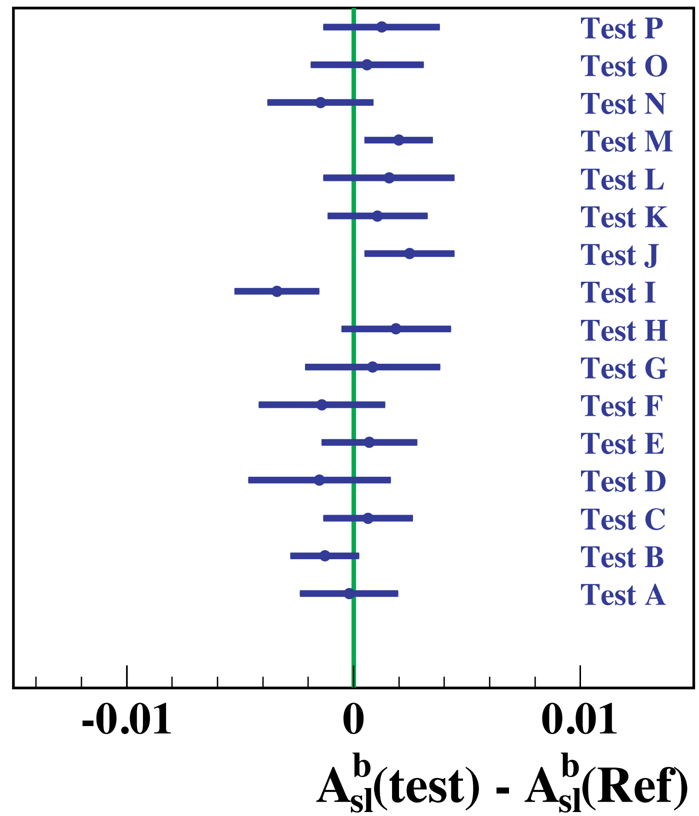
  Loosen cuts, more background, should get consistent result (but usually with larger uncertainty)

  Change cuts, change histogram binning, change borders …

  Change parameterizations, change fit techniques

Systematic Uncertainties

- Define a pass/fail criteria before the consistency checks. Remember with 20 checks you expect on average one 2 deviation
- if you do not expect a systematic effect a priori and if the deviation is not significant (judgment call), then do not add this to the systematic uncertainty
- If there is a deviation, try to understand it, correct for it, or fix the mistake



Systematic Uncertainties

e.g., top quark mass

Source of systematic uncertainty	Magnitude (GeV/c^2)
Residual JES	0.42
b-JES	0.60
Generator	0.19
ISR	0.72
FSR	0.76
b-tag E_T dependence	0.31
Background composition	0.21
PDF	0.12
Monte Carlo statistics	0.04
Lepton p_T scale factor	0.22
Multiple Interactions	0.05
Total	1.36

Possible Variation with E_T or (change by ±1□)

How different from light quarks?

PYTHIA vs. HERWIG

Vary parameters in generator

Change by ±1□ in estimated efficiency

Change backgrounds by estimated undertainties and vary model of W+jets

Divide sample

Shift lepton p_T by ±1%

Room for MC not to model properly

- Each line may mean re-running the full analysis many times; you will be re-running your full analysis chain *way* more than you think

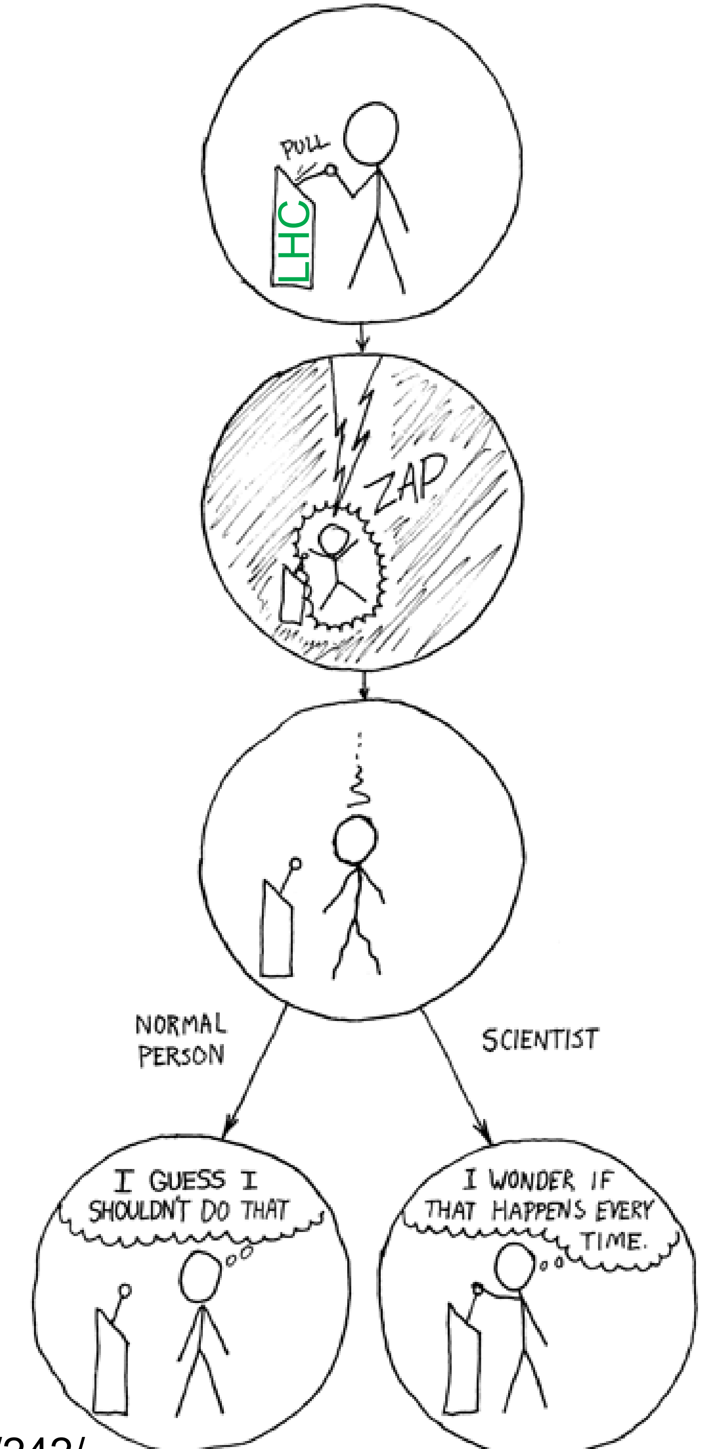
Automate that chain as soon as possible!!

In Closing

Only a tiny survey with some examples;
huge amount of experimental
techniques there "on the streets"
– just get out there and do it

Always keep in mind
that you are physicists;
these huge $B machines were
built to get at the physics
that you are now directly
responsible for extracting
as part of your day-to-day lives

Seize the opportunity,
do a great job,
and have fun!



http://xkcd.com/242/